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Meta-Heuristics Analysis for Technologically Complex Programs: Understanding the Impact of Total Constraints for Schedule, Quality and Cost

Henry Darrel Webb
Old Dominion University

META-HEURISTICS ANALYSIS FOR TECHNOLOGICALLY COMPLEX PROGRAMS: UNDERSTANDING THE IMPACT OF TOTAL CONSTRAINTS FOR SCHEDULE, QUALITY AND COST

by

Henry Darrel Webb
B.S. September 1984, University of Southern Mississippi
M.E.M. December 2008, Old Dominion University

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Approved by:

Patrick Hester (Director)

Rafael Landaeta (Member)

Holly Handley (Member)

Ray Paul (Member)

ABSTRACT

META-HEURISTICS ANALYSIS FOR TECHNOLOGICALLY COMPLEX PROGRAMS: UNDERSTANDING THE IMPACT OF ABSOLUTE CONSTRAINTS FOR SCHEDULE, QUALITY AND COST

Henry Darrel Webb
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Advisor: Dr. Patrick Hester

Program management data associated with a technically complex radio frequency electronics base communication system has been collected and analyzed to identify heuristics which may be utilized in addition to existing processes and procedures to provide indicators that a program is trending to failure. Analysis of the collected data includes detailed schedule analysis, detailed earned value management analysis and defect analysis within the framework of a Firm Fixed Price (FFP) incentive fee contract.

This project develops heuristics and provides recommendations for analysis of complex project management efforts such as those discussed herein. The analysis of the effects of the constraints on management of the program indicate that, unless unambiguous program management controls are applied very early to milestone execution and risk management, then plans, schedules, tasks, and resource allocation will not be successful in controlling the constraints of schedule, quality or cost.

The author would like to dedicate this to the people that have given unselfishly during the prior six years that it has taken to complete the Masters and Doctorial work. The author would also like to thank my wife, Joyce, and children, Justin and Rachael, for their kind understanding when playtime was over and work took precedence.

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There are many people who have contributed to the successful completion of this project. The author is indebted to more people in the academic community, the Department of Defense and industry than can be acknowledged individually. Without this cooperation, guidance, experience and contribution of time, the research associated with this effort could not have been successful.

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It is important to recognize that this report represents the views, conclusions and recommendations of the author and has not been officially approved by any Department of Defense staff or agency.

NOMENCLATURE

ACWP	Actual Cost of Work Performed
AHP	Analytic Hierarchy Process
AMρ	Actual Milestones Complete Ratio
ANSI	American National Standards Institute
ARA	Acquisition, Resources and Analysis
AT&L	Acquisition, Technology and Logistics
BAC	Budget At Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budget Cost of Work Scheduled
CBB	Contract Budget Base
CDRL	Contract Data Requirements List
CPAF	Cost-Plus Award Fee
CPI	Cost Performance Index
CPM	Critical Path Method
CV	Cost Variance
D	Detection
DARPA	Defense Advanced Research Projects Agency
DUSD	Deputy Undersecretary of Defense
DLA	Defense Logistics Agency
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
EAC	Estimate At Completion
EIA	Electrical Industries Association
ETC	Estimate To Complete
EVM	Earned Value Management
EVMS	Earned Value Management System
FARS	Federal Acquisition Regulations
FCM	Fuzzy C- Means
FMEA	Failure Modes Effects Analysis

FMM	Fuzzy Markov Model
FMρ	Future Milestones completed ratio
FPIF	Fixed Price Incentive Fee
FRP	Full Rate Production
IMδ	Incomplete Milestones Delta
IMρ	Incomplete Milestones Ratio
IMS	Integrated Management System
IT	Information Technology
Ma	Planned Milestones Actually Completed
Mf	Future Milestones completed
Mp	Milestones Planned
MPI	Milestone Progress Indicator
Mt	Milestones Total
MTp	Total milestones planned for completion
NCC	Negotiated Contract Cost
O	Occurrence
OMB	Office of Management and Budget
PMBOK	Project Management Book Of Knowledge
RAI	Resource Allocation Indicator
RFEBC	Radio Frequency Electronics Base Communication
RPC	Risk Priority Category
RPN	Risk Prioritization Number
S	Severity
SV	Schedule Variance
SIMδ	Sum of the Incomplete Milestones Delta
SPI	Schedule Performance Index
US	United States
USAF	United States Air Force
WBS	Work Breakdown Structure

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DISCLAIMER

CHAPTER 1

INTRODUCTION

1.1 COURSES OF ACTION

"Despite significant study and corrective effort over a period of two decades, the defense system acquisition process in the U.S. continues to be plagued with major cost overruns, schedule slippages, and hardware performance deficiencies"(Lochry et al., 1971, p. 1). The above quote from the USAF Academy Risk Analysis Study Team's observations in 1971 indicate that Government large-scale acquisition programs violate the constraints of cost, schedule and quality despite efforts that are driven from levels of the Secretary of Defense downward. As an answer to problems associated with software development in the early 1970s, the landmark book *The Mythical Man-Month Essays on Software Engineering* was authored by Frederick Brooks Junior. In the *Mythical Man-Month*, Brooks (1975) writes that there is no scene quite so vivid as the mortal struggles of great beasts in the tar pit:

> Large and small, massive or wiry, team after team has become entangled in the tar. No one thing seems to cause the difficulty – any particular paw can be pulled away. But the accumulation of simultaneous and interacting factors brings slower and slower motion. Everyone seems to have been surprised by the stickiness of the problem, and it is hard to discern the nature of it. But we must try to understand if we are to solve it (p. 4).

Although forty years have passed, these issues still remain. Large-scale acquisition programs appear related to these tar pits. Obviously, technology and knowledge have changed since the 1970s. So this begs the question, why is it that technically complex programs face these issues today? From a psychological standpoint, forty years is a nanosecond in human evolution. The problems that are faced today continue to be addressed in the same fashion as in the past. Program managers utilize current technology and methods to address cost and schedule risk. Kerzner (2006) states that when program managers only use cost and schedule analysis, there is a likelihood that identification of the real problem will go undetected. Therefore, even though enhanced knowledge and decision-making strategies may have been developed over this period, decision-making and program management must still be learned by each generation of technologists and managers.

It is this learning process that defines decision-making. According to Lu, Zhang, Ruan, Wu (2006), it is this cognitive process which leads to the selection of a course of action among alternatives to choose a solution. Every decision making process includes a process to reduce the number of alternatives, which leads to a final alternative selection. Decision making can be seen as a reasoning process, which can be rational or irrational, and which may be based on explicit or tacit assumptions. While it is not the intention of the author to determine if decisions are rational or irrational, or to form a complete solution and make decisions for the program under study, it is the data used to form decisions, as well as the decision making processes and conditions resulting from those decisions, which are of interest in this research.

The author has provided program management support to a Department of Defense military command to develop and field a radio frequency electronics base communication (RFEBC) system which has encountered schedule, cost and quality problems. The author started work on this program in October 2009 and has documented the program efforts since that date.

Program data has been collected and analyzed to identify heuristics which may be utilized, in addition to existing processes and procedures, to provide early indicators that a program is trending to failure. Additionally, data has been collected which represent the managerial aspects of the tasks performed during this time period which will be used to analyze potential strategies to provide enhanced heuristics for decision-making events in similarly complex programs in the future. Analysis of the collected data includes detailed schedule analysis, detailed Earned Value Management (EVM) analysis and product defect analysis within the framework of a Firm-Fixed Price Incentive Fee (FPIF) contract.

The analysis of program and contractual constraints on management of the program indicate that, unless explicit attention is applied to risk management and requirements management, then program plans, schedules, tasks, and resource allocation decisions by program management will not be successful in controlling the constraints of schedule, product scope or cost thus creating a crisis in the program. Enhancing the ability to make informed decisions is the prime objective for analyzing data in this project. Therefore, one must understand how decisions are made and the prioritization of decisions in order to provide coherent and productive guidance to diminish the likelihood of potential crises.

1.2 GENERAL INFORMATION

This project supports and brings to a conclusion efforts which have been executed for the past twenty-four (24) months, where the author has performed tasking and provided support to a Department of Defense command to develop, place into production and field RFEBC systems.

1.2.1 Doctor of Engineering Planning, Analysis & Reporting

The knowledge and information gathered from the efforts listed below have been used to support the development of the documentation for this Doctor of Engineering project:

- Verifying that engineering activities and tasks are executed
- Participating in program management reviews
- Providing contract execution support
- Providing program review briefings
- Providing monthly financial analysis

The following efforts have supported the Doctor of Engineering project data analysis:

- Serving as the lead reviewer for all software deliverables
- Participating in software and engineering architecture assessment meetings
- Participating in program management review meetings
- Participating in earned value management & schedule progress meetings

Program contract deliverables have been incorporated into the reporting of this study. The contract deliverables provided copious data for evaluation. One of the most difficult decisions that the author made was how to reduce the data to determine if there were indicators which could be analyzed for significance against existing knowledge based upon program scheduling, cost estimation, decision-making strategies and methods, and program management knowledge bases such as the Program Management Book of Knowledge (PMBOK).

Thus, the reporting of this study was made easier through the development of the initial study proposal which has guided the investigation of this project.

1.2.2 Project Background

The RFEBC development began in 1996 by the Defense Advanced Research Projects Agency (DARPA). DARPA performed an open market solicitation where three vendors responded and one was selected to develop the system. Prior to 2006, the program transitioned to the United States Navy. In 2006, the program sponsor awarded a follow-on Cost Plus Award Fee (CPAF) contract to a prime contractor to transition from systems development to initial production. This program continued development of the RFEBC system until 2009. A second vendor was awarded the Full Rate Production (FRP) Firm-Fixed Price Incentive Fee (FPIF) contract in 2009.

This contract specified the cost, delivery schedule and requirements for which the vendor was responsible and effectively placed constraints on the vendor to ensure that the systems were delivered with a specific set of attributes and capabilities, with a set delivery date and a set cost. This type of contract places maximum risk and full responsibility for all costs and resulting profit or loss on the vendor and effectively locks the vendor into a situation where concessions could be required should the vendor violate the contract constraints.

The analysis of the constraints on management of the program indicate that, unless explicit attention is applied to risk management and requirements analysis, program plans, schedules, tasks, and resource allocation, then program management will not be successful in controlling the constraints of schedule, quality or cost.

1.3 PURPOSE

The decision making process is fraught with inconsistencies and exceptions. People use their existing worldviews to judge information and situations in which they make decisions. People generally follow thinking and values that conform to their existing beliefs. The implication in the above statement, from the world of systems theory, is that participants in engineering management, given their disparate goals could exhibit inconsistencies and fallibility as their worldviews require alteration or are challenged in situations where knowledge is incomplete or data is technically complex. This situation could force decision-makers to formulate decisions that are based on incomplete understanding of the topics and therefore incorrectly execute program management decisions.

This project will investigate the balance between the two primary information sources available for engineering management professionals to make decisions. The first source of information is financial data and reporting of projects identified in the cost management section. The second source is technical data and progress indicators identified in the technical management section. Given that earned value management progress indicators demonstrate insufficiencies to predict cost and schedule overruns in the investigated program, this Doctor of Engineering project will provide guidance regarding proposed heuristics to utilize in addition to standard program evaluation tools.

1.4 PROBLEM

Acquisition programs in the Department of Defense, where procurement of large-scale military systems is an ongoing activity, require explicit communication between the government and the vendor. Given that personal interactions occur on a day-to-day basis, real world problems require that a program manager reflect on problems which require decisions. This reflection requires understanding the overall structure of the problem as well as preferences and beliefs.

Explicit communication mechanisms are defined along with associated regulations in the Federal Acquisition Regulations (FARs)(Defense Logistics Agency, 2011). Even though the FARs provide legislation and guidance for governmental procurements, and address specific processes for interaction between the vendor and the government, program management issues still need to be addressed between the government and vendor program managers where verbal and electronic email communication are the main mechanisms for exchanging information. These mechanisms are a source of miscommunication and cause problems to escalate to crisis if there is no common understanding of the conditions which have occurred.

1.5 HYPOTHESIS GENERATION

Decision-making interactions occur on a day-to-day basis between government and vendor program managers, it is through insight and understanding that decision-making efforts can be improved.

It is the researcher's intent to understand the relationships between program data and decision-making related to engineering management implementation in complex and problematic programs. This understanding includes facets of program management, financial management and resource allocation. The conditions placed on the program of interest in this document have constraints of cost, schedule and scope/quality predetermined. This means that the cost, schedule, and scope of the contract are negotiated and firmly established. Since the contract is a firm-fixed price procurement, these constraints should all be defined as precisely as possible. The hypothesis is that the program will fail to maintain at least one of the constraints identified above because the program still has subsystems which require developmental efforts.

It is also hypothesized that strategies exist which allow for the exploration and analysis of additional metrics for the above constraints such that methods may be identified and proposed for inclusion as complementary decision-making aids. It is proposed that meta-heuristics provide one such strategy as an additional decision-making aid. Additionally, guidance for the utilization of the developed heuristics will be presented to provide closure for this project.

1.6 RESEARCH SIGNIFICANCE

Organizations, just like individuals, act rationally accordingly to their perceived worldview. However, few are able to enjoy the perspective of a detached observer when circumstances preclude an objective viewpoint. Bausch (1997) indicates that people will make decisions based on incomplete understanding of the moment, then after reflection, will change their decision. How many times have we bought an item, on impulse, and then returned the item to the vendor? Our need to make decisions is similar to impulse buying; many times the decision is returned to the decision-maker after further consideration or when new information is forthcoming. Rethinking a decision should occur when new information is available, especially when decisions require the most explicit communications (Arbogast, 2007; Beresford, Katzenbach, & Rogers Jr, 2003) to promote healthy governance practices in decision making. Inadequate decision-making not only happens in personal decision-making, but is also prevalent in group decision making and generally attributed to groupthink (Boland & Corinis, 2005), lack of communication or lack of understanding (Bodurtha, 2003).

Communication complexity and lack of understanding are found in all aspects of life and are manifest in the business world. Lawyers make fortunes adjudicating communications between businesses.

Reflections on problematic aspects of human language communication were captured by the 19th century philosopher Ludwig Wittgenstein:

> In everyday language it very frequently happens that the same word has different modes of signification--and so belongs to different symbols--or that two words that have different modes of signification are employed in propositions in what is superficially the same way. Thus the word 'is' figures as the copula, as a sign for identity, and as an expression for existence; 'exist' figures as an intransitive verb like 'go', and 'identical' as an adjective; we speak of something, but also of something's happening. In the proposition, 'Green is green'—where the first word is the proper name of a person and the last an adjective--these words do not merely have different meanings: they are different symbols (1918, p. 13).

Communication is a significant component in the framework for decision-making both verbally and visually. This multiplicity of meanings was employed in 1998 by former President Clinton during testimony before a grand jury in rationalizing the word "is".

Additionally, as is demonstrated by analyzing Figure 1, even to believe that two people see the same thing is problematic.

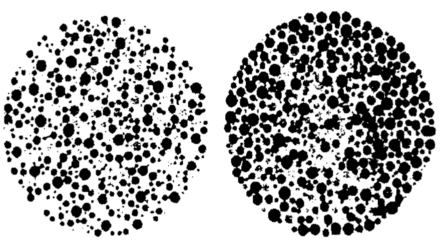

Figure 1. Ishihara Color Blind Test-Numbers Adapted from (Fluck, 2006).

To provide an example, several people discuss the particular details about the two forms in Figure 1. Each person is asked to add the numbers. The first says the answer is 94, the second answers 91, the third answers 12, a fourth person inquires "What numbers?" Here the author has outlined an example of a physical difference in perception. With the exception of the first person all others are somewhat colorblind and therefore do not perceive the subtle differences in shading that the first person perceived. This situation is simulated in the monochrome version of the colorblindness test in Figure 1.

The musings of Wittgenstein, testimony by Clinton and this simple example highlight differences in perception and bring into focus the problems inherent in communication and lack of understanding in complex situations.

The ability to provide succinct communication appears to be diminished drastically when there is no common ground or common standards for discussing complex and intricate technical information. People utilize familiar data and review existing situations instead of applying techniques and methods to develop an informed decision, especially when uncertainty includes deficits of information and lack of technical knowledge.

1.7 RESEARCH CONSTRUCTS & ETHICS

In an applied research project where context is important to describe conditions that exist in the qualitative analysis, the cycle of research for qualitative research as identified by Munck (1998) has been followed during the phases of the research. The following aspects of ethics from Trochim & Donnelly(2007) have been addressed:

- Confidentiality
- Anonymity
- Informed consent
- Rights to service.

Per directives from the sponsor, no attribution data will be used in any products resulting from this research. Additionally, there will be no attribution or personal information associated with any information provided in this document.

1.8 DELIMITATIONS AND LIMITATIONS

Because completing comprehensive assessments for all potential effects, even at reduced detailed levels of modeling, simulation, sophistication and disaggregation, would require impossibly large amounts of time, data, knowledge, and resources, every study must be limited in some aspects. The considerations below address the limits and delimitations for this project.

1.8.1 Delimitations

Selecting the appropriate scope of the research and choosing methodologies and data to support the research goal was crucial to meeting the expectations of the program stakeholders. In this effort, the author has restricted analysis of data to one major function of program management: the successful completion of the program. The data collection effort was accomplished through the initial discussions with the sponsor, cost analysts and program schedulers who have expertise in the areas of proposed analysis: evaluation of schedule characteristics, EVM data and defect data such as task duration, work allocated, resources allocated, cost variance trends and defect correction characteristics.

The evaluation also was required to be non-attributable to any specific US Navy program and required to be consistent with regulations and policies of the US Navy. Therefore, only data and information which has been sanitized and normalized could be used for evaluation. Even though data were collected as contract deliverables, the data reduction effort still required many weeks of analysis to support the findings for this project.

1.8.2 Limitations

When dealing with hard decisions, many decision spaces lack sufficient depth to make an empirical valuation. Simple decision-making methodologies prove inadequate when complex system attributes are not substantiated with significant robust data. Also, uncertainty associated with scarce data can come from numerous sources and can be difficult to reduce for various reasons. One issue is the inability to collect data given the complexity and expense of modeling the system.

Additionally, there are issues when addressing a problem at the boundary conditions. Complex boundary conditions of the problem space do not make simple compensatory evaluation techniques feasible nor will they produce significant results. Having said this, the complexity associated with decision-making evaluations does not lend itself to simple system state condition methodologies such as crisp data clustering or Markov system state analysis.

Meta-heuristics are new-generation heuristic algorithms used to assess difficult combinatorial problems whose dimensions in real life applications prevent the use of exact approaches (Paolucci, 2006). The literature review will address these techniques and will be used in this project to reduce the limitations and provide for the collection of empirical data and the modeling. The analysis of the data will be used to substantiate validity and generalization of the findings.

1.8.2.1 Validity

Validity encompasses the entire experimental concept and establishes whether the results obtained meet the requirements of the scientific research method.

Trochim and Donnelly (2007) indicate that internal validity dictates how an experimental design is structured and encompasses all of the steps of the scientific research method and addresses the issues of alternative causes potentially corrupting observations or results. Internal validity is supported in this project given that the literature search provided many examples of analysis of schedules and cost data evaluations in program management research.

The extent to which the research successfully contributes to the body of knowledge is addressed by Leedy and Ormrod (2005), in which external validity is the process of examining the results and questioning whether there are other alternative relationships which may be affecting the results. Any scientific research design only puts forward a possible cause for the studied effect. There is always the chance that other unknown factors may contribute to the results and findings.

External validity is supported in this project through the use of existing methods and techniques where the duration of tasks, work allocated to tasks and resource allocation data that are to be analyzed, have been utilized in prior works and supports the body of knowledge for program management.

1.8.2.2 Generalization

The project has been designed to contribute to the generalized knowledge base of program management. The analysis of schedule characteristics will produce empirical results which will form a matrix of results from which findings can be made. However, generalization is a more problematic issue in this project given that there do not appear to be (Senglaub & Bahill, 1995) formal mathematical theorems which can be used to validate models based on fuzzy techniques. Generalizing the output of fuzzy technologies in a project such as this is difficult where the problem solutions form a solution space where the problem is affected by the potential solution and is not generally repeatable.

Utilizing multi-criteria decision making methods and software, where the characteristics of decisions and problems can be adjusted and repeated, will facilitate increasing the generalization of the findings through repeatability.

Ensuring generalization when designing a solution is more difficult since we may only be able to bound the problem by identifying uncertainties from which the crisis arose. The methods that have been selected appear to lend themselves to assessing the efficacy of solutions, where we can answer the question: did the solution improve the situation problem space characteristics such as reduce task duration, improve resource allocation conditions, or improve cost variances? This can only be known by reviewing the products of the empirical analysis and including contextual issues of the problem.

1.9 REPORTING OF THE RESEARCH

This formal report has been generated and contains contextual information, a literature review, a presentation of the research under investigation, a presentation of the quantified results, and a discussion of the results. This formal report also includes graphical representations of the data for interpretation. The graphical representations include graphs, histograms, charts and tables as necessary to adequately describe and present data and findings.

In this project, research methods in the field of engineering management will be used to analyze information collected during the execution of the program. The project has been organized to first detail the environment of the program, then through a literature search, investigate the central concepts of programmatic decision making, including issues of uncertainty. The literature review will include a discussion of heuristics and software metrics to aid decision-making. Secondly, data collection methods will be discussed. Thirdly, a framework will be presented for an unbiased and objective analysis of the associated data. Fourthly, the results of the analysis will be presented.

To support the above representations, data and specific program decisions have been collected and processed. Program schedules along with EVM calculations and defect information were processed to sanitize attribution information. These data were then reviewed for anomalies. Finally, the report of this project will close with conclusions and potential future research issues.

CHAPTER 2

BACKGROUND OF THE STUDY

2.1 LITERATURE REVIEW

Existing literature was gathered and analyzed for this study to understand the program phenomena and constructs for data analysis. Many documents on topics of significance to the research were collected and reviewed (approximately 330 documents) for inclusion in this document. Many documents were reviewed and not included in the document (approximately 200 of the 330 were not considered applicable for reference).

2.2 PROGRAM MANAGEMENT

While the focus of this literature review is to identify heuristics for the analysis of programmatic and financial data, this research facilitates risk and crisis project management efforts associated with the program under study. To be able to successfully analyze the data, one must understand the associations of the data to risk and crisis project management efforts. Batson (1987) provides the following quote made by Major General John R Guthrie on the subject of risk management:

> The most rudimentary sort of good risk analysis might have enabled us to avoid most of the pitfalls we have encountered. By rudimentary I mean – did we identify those items which were new and identify the impact on overall system performance if that particular component or subsystem were to experience difficulty? (pp. III-1)

This question, asked by General Guthrie, highlighted issues where Congressional skepticism and loss of funding for large scale military programs pressed program managers to search for methods and techniques to control cost growth and schedule delays in the 1970s. Many new sources of information have been developed since the issues of DoD programs spurred the speech at the DoD Managers' Conference.

These same problems continue to be experienced today and are expected to continue in the future (Kerzner, 2006). This is especially true in DoD programs where systems have become more complex and the fiscal environment more unstable. Therefore, the need to understand the problems that lead to cost growth and schedule delay is more imperative than forty years ago. Literature from the 1960s and 1970s support documentation that is being produced today. It is an imperative that program managers learn from yesterday's problems, in order to solve today's problems. It is through the teachings and works of people that have experienced similar environments that we learn without having to personally experience the agony of program failure.

The literature review of topics related to the research for this project follows this introduction. Many documents have been collected on the topics which are pertinent to those delineated in Chapters 3, 4, and 5, including decision-making in complex situations where uncertainty and vagueness are commonplace in risk analysis.

These topics have been supplemented with additional documents collected and archived over the past twelve months which have specific applicability to the research efforts associated with the program under study. These topics include existing program conditions, such as the type of contracts and regulations that are used in DoD acquisition programs, program evaluation tools such as earned value management, schedule development and analysis, failure mode effects analysis and program metrics.

To complete the review topics, meta-heuristics will be discussed, including topics on fuzzy logic, fuzzy modeling, and fuzzy Markov systems and analysis. Data clustering, along with the above topics, will be investigated for applicability in analysis of the program data. The topic-specific documentation will support the data analysis efforts outlined in the data analysis chapter.

2.3 CERTAINTY AND DECISION MAKING

The most common problems in program management are problems associated with planning and problems of identifying actions that successfully reduce the uncertainty between the current program state and future program states. The concept of decision-making processes analyzed throughout this project owes considerable debt to Simon (1947, 1955). Decision-making mainly concerns the cognitive activities of an individual, the decision-maker, facing a question for which no automatic reply is readily available. Most of the literature around this concept is based on the hypothesis that such cognitive activities are scientifically observable and that "patterns" of "decision behaviour" can be established

(Kahneman & Tversky, 1979; Montgomery & Svenson, 1976; Slovic & Tversky, 1974).

2.3.1 Certainty

Byrns (2011) describes certainty as an aspect of complete information, which entails obtaining precise knowledge of current and all future values of variables, and uncertainty as the state of a variable when the current or future values of that variable are not known with precision. Organizations and individuals try to achieve a state of certainty when attempting to make decisions. A state of certainty has proven to be unobtainable, given that the future state of any situation, event, problem or condition cannot be known explicitly with a probability approaching one hundred percent.

Assuming that uncertainty is a factor to some degree in all human endeavors, decision-making also contains uncertainty. Uncertainty in decision-making leads to difficulty when individuals and organizations try to make informed decisions concerning future events. This uncertainty is manifest as organizations attempt to achieve goals and objectives of stakeholders. Organizations use program management and decision-making as tools to achieve these goals and objectives. Lu, et al. (2006) and Kerzner (2006) describe how organizations achieve their goals through the use of resources such as people, material, money, and the performance of managerial functions such as planning, organizing, directing, and controlling.

2.3.2 Complexity of Decisions

Clemen (1996) asks the question, "What makes decisions hard?" (p. 2). Certainly, different problems involve different difficulties. Every decision may have its own special problem and, therefore, significant and independent sources of complexity. Clemen (1996) answers the above question by stating that a decision can be hard simply because of its complexity since keeping all of the issues in mind is nearly impossible. Additionally, decisions can be difficult because of the inherent uncertainty in the situation, while in some decisions, the main issue is uncertainty. In highly complex problems, multiple objectives may cause a problem to be difficult to solve. A decision maker may be interested in working toward multiple objectives, where achieving one objective may inhibit another objective.

2.3.3 Decision Analysis

Decision analysis provides effective methods for organizing complex problems into structures that can be analyzed. Structuring tools identified by Taylor (2007) include decision trees, the Analytic Hierarchy Process, and influence diagrams. Additionally, failure modes effects analyses and analytical prioritization processes, have been used in analyzing the formulation of problems to find solutions through fuzzy decision-making techniques (Kwok, Zhou, Zhang, & Ma, 2007; Lu, et al., 2006; Xi, 2011). By identifying important sources of uncertainty and representing that uncertainty in a systemic fashion, a decision-maker can make trade-off and risk versus benefits analyses where one objective is leveraged against another. Additionally, decisions and trade-offs can be made between expected return and riskiness for individual solutions. Clemen (1996, p. 1) asks two additional questions that are pertinent to this research: "Have you ever had a difficult decision to make? ... Did you end up making the decision based on intuition or on a hunch that seemed correct?" The fact is that hard decisions are just that, hard, and do not allow individuals or organizations the luxury of time and resources to solve these problems in a conventional fashion, thus introducing risk and the potential for making an uninformed decision.

So the question is posed, how can you determine if you can make a good decision? A decision could be considered good if it was made where all available information was analyzed and systematic reflection was given to goals and probable outcomes. Even then, the decision-maker can only be so sure that a good decision has been made. Potentially, the decision-maker, while an expert in their field, may not have the knowledge or be aware of tools that may help in the decision-making process. Decision analysis can help the decision-maker comprehend problems and allow for more informed decisions. Further study in the area of risk management has been undertaken during this literature search. The following sections of this chapter will discuss and highlight methodologies and processes that may also be used in the decision-making process.

As we seek to improve the effectiveness of actions in pursuit of positive outcomes in decision making, it becomes ever more difficult to grasp and identify the boundaries of complex situations.

2.4 COMPLEX SITUATIONS

As we become more sophisticated about the complexity and workings of situations which contain socio-technical aspects, the boundaries of complex environments flex and change to adapt to the constraints which bound them. The program manager must be adaptive and develop abilities to make decisions and develop solutions.

2.4.1 Complex Properties

How does a decision maker determine when a situation or problem has become too complex to grasp? Sousa-Poza (2008) addresses conditions which are necessary to address complex situations. There is a need to provide a separation between perspective and reality and addresses the issue of fallibility. Reality must be discussed in the context of a model which is limited and bounded by many axes. These axes may be orthogonal and include socio-technical situations which augment the complexity of the situation or the analysis of the complexity of a system.

Complex properties and conditions are not represented by the complete understanding of a complex situation or by sum of the parts of a complex system. The conditions of emergence and multiplicity ensure that program management contains difficult problems. These problems are not addressable by changing the schedule or adding resources or providing additional funding, which are the three main choices that program managers have as alternatives to reduce risk in a program. In program management, as information and data are gathered, change will occur in plans and schedules such that the original conditions of the problem space will not reoccur. Therefore, uncertainty and equiprobability will dominate the outcomes of poorly examined complex situations.

Prior to the present day development of constructs concerning complexity, Rittel & Webber (1973) propose that problem understanding and problem resolution are connected to each other, and go further to state that, in order to anticipate the solution space for a complex problem and anticipate the resolution ahead of time, knowledge of all feasible solutions is required. The very nature of complex problems would appear to prevent this ability to know all which, the author believes, contradicts the prior assertion that detailed knowledge of all feasible solutions is attainable.

In contrast to Rittel and Webber's position, Conklin (2006) takes a very different view of understanding and development of solution spaces for program management. Conklin (2006) addresses the complexity of gathering information about complex problems through the use of facilitation processes and associated tools. Conklin has developed a facilitation process and associated tools for capturing information and issues called dialogue mapping. Dialogue mapping acts as a tool to capture the non-linear thinking processes used by humans to address wicked problems and achieve complex goals.

2.4.2 Complex Goals

Dialogue mapping is just one method available to address complex problems. There are multiple ways to address complex problems and goals in program management. These include milestone driven, decomposition by cases, guarded introduction, divide and conquer and other refinements which may be used to operationalize and develop a goal.

Considering the current demands to increase productivity and quality, it shouldn't be surprising that there is keen interest to apply decision making concepts to program management and complex systems of systems (Kobryn & Sibbald, 2004).

Successful program development involves a complex set of interactions between various human and mechanical components. Each component has many different dimensions and attributes. The successful functioning of the program depends upon all of these components interacting in a predictable and desirable manner. This interaction can be defined as the union of several sets, an idea adapted from Tsoukiàs (2007).

Given that a set of possible solutions S = {P,S,R} where

- *P* is the set of participants (Stakeholders and their preferences) to the decision process;
- *S* is the set of stakes each participant brings within the decision process;
- *R* is the set of resources the participants commit on their stakes and the other participants' stakes.

The representation of this triplet of subjective components is not fixed for all sets within the decision making process, but usually will evolve throughout the decision making process making the set S dynamic, and therefore, inducing complexity. The socio-technical system of interacting elements which generates a multi-temporal condition will also generate a multi-decision condition in which uncertainty about the future allows modifications and interaction with the domain environment therefore changing initial assumptions. These changes are dampened in a group dynamic by preferences of the decision makers, whose preferences act as anchors in goal refinement.

2.4.3 Complex Organizations

Preferences are becoming of greater interest in many areas such as decision making, multi-agent systems, constraint satisfaction, and decision-theoretic planning as in the work of Kaci and van der Torre (2008), Jackson (2003) and Allen, Strathern, and Baldwin (2007). One of the characteristics of preferences in groups is that of emergence. If left to their own devices, organizations and teams exhibit the characteristic of self-organization. Figure 2 below highlights this tendency where resources will form synergistic alliances which may not provide the most efficient conditions to meet goals and objectives to ensure program success.

Therefore, it is important to utilize some form of framework to guide the group. The influence of preferences and biases are reduced in the Department of Defense procurements through the regulations and guidance that has been provided in the form of the DOD Architecture Framework (DODAF), Earned Value Management and specification of contract types.

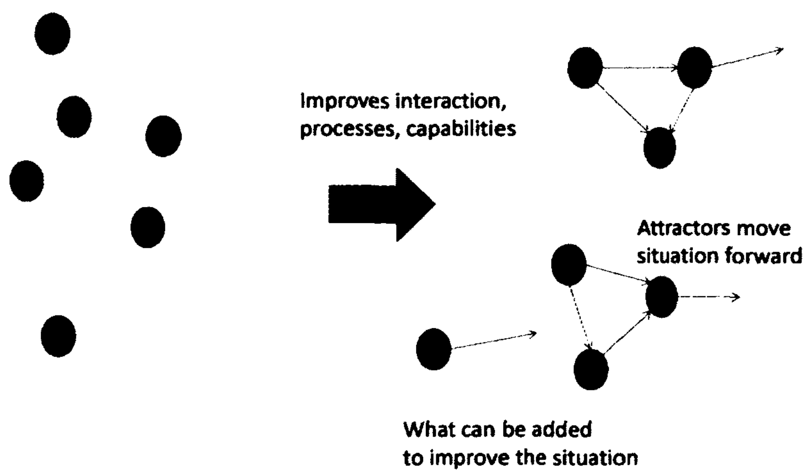

Figure 2. Self-Organization Adapted from (Allen, et al., 2007, p. 423).

However, this guidance does not necessarily apply to the commercial world, thus introducing a dichotomy between the government and the vendor, and also introducing risk and uncertainty in program management. This dichotomy causes difficulty in programs given that the government and vendor have multiple objectives which may conflict. One objective that is inherently conflict oriented is the vendor's goal to make as much profit as possible which may be in opposition to the government's goal of getting the best product possible.

2.5 RISK

The lack of risk and uncertainty planning can result in financial disaster. The following section begins with a brief review of risk planning and management and defines risk in terms relevant to program management. There are many techniques available to successfully execute risk analysis and mitigation. The following discussion is meant merely to serve as a reference and provide basic concepts of risk management which have been used during the execution of the program under study.

Holton (2004) discusses the differences in philosophies between Keynes and Knight on the differentiation of risk and uncertainty. Knight takes the position that risk relates to objective probabilities and uncertainty relates to subjective probabilities. This project utilizes this distinction as a basis for further exploration of risk.

Additional references provide a much more detailed discussion and framework for developing risk analysis programs (Carbone & Tippett, 2004; Chang, Wei, & Lee, 1999; Defense Systems Management College, 1989; Department of Defense, 1980; Fowlkes, Neville, Hoffman, & Zachary, 2007; Frenklach, Packard, & Seiler, 2002; Galway, 2004; Garvey, 2009; Hulett, 2005; Huntsberger & Billingsly, 1979; Lochry, et al., 1971; Long, 1985; Miller & Freund, 1985; Norris, Perry, & Simon, 2000; Parsons, 2003; Puente, Pinol, Priore, & Fuente, 2002; Smith, 2003; Stoneburner, Goguen, & Feringa, 2002; Walewski & Gibson, 2003; Wiegers, 2002).

To reduce risk in estimation decisions, participants should first agree on the factors influencing goals, objectives and criterion and then identify the factors judged to be the most useful to address efforts that are to be undertaken. Generally, technical information should be used to analyze issues and to stimulate discussions. Technical specialists should develop measures and provide information, diagrams and objectives to accomplish the goals of the decision-making process. Non-technical participants should provide suggestions to help understand the logic represented by outside influences such as business constraints and contracts (Walewski & Gibson, 2003).

The following sections describe the difference between risk as an objective constraint and uncertainty as a subjective constraint. It has long been recognized that there is a distinction between risk, where probabilities are known, and uncertainty, where probabilities are unknown. This differentiation must be handled in separate ways.

2.5.1 Crisp Risk Analysis

Recently, Byrns (2011) differentiates crisp risk as the statistical distribution of alternative outcomes from an action which is usually characterized by the variance, standard deviation and other characteristics of the possible outcomes such as schedule and cost variance. If the probabilities of alternative outcomes are reasonably well known, a probability function can be constructed. Given that risk can be quantified and planned for, it can be used as data for program planning.

2.5.2 Uncertain Risk Analysis

Uncertainty in program management planning is a situation where current information or historical data appear useful in predicting certain outcomes. However, conditions may exist where data appear unstable or do not exhibit completely known distributions. Knightian uncertainty exists when the probability functions for certain broad classes of rare or exceedingly speculative events are a matter of relatively uninformed guesswork, such as the estimates that are used at the beginning of a program to develop budgets and schedules. Byrns (2011) points out that by point *f* in Figure 3, estimating the likelihood of a possible event is almost pure speculation.

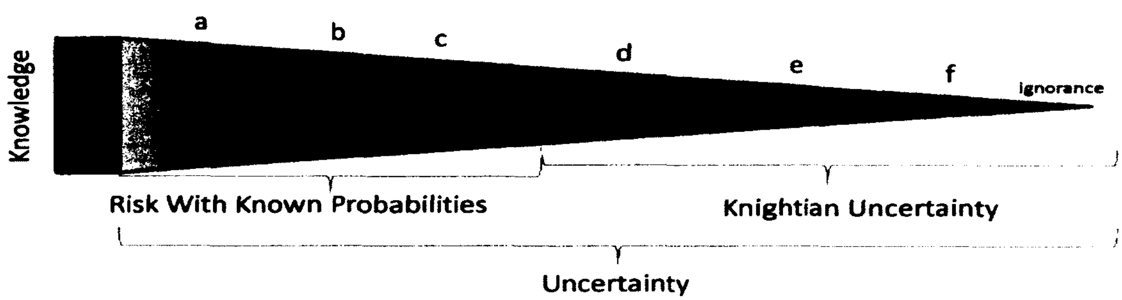

Figure 3. Range Of Uncertainty and Risk Adapted from (Byrns, 2011).

The obvious solution is to develop risk plans and to identify uncertainty that may be mitigated by proper program management techniques. Uncertainty may be used as input for program planning, but must be derived in an alternative fashion. The program manager must be able to differentiate the conditions of risk and uncertainty and develop measures to provide indications that the program is entering a risky or uncertain phase. Programmatic metrics were developed for this purpose and are discussed in the next section.

2.6 METRICS

Why should programs, especially software development programs, use metrics? Brooks (1975, p. 15) states that "incompleteness and inconsistencies of our ideas become clear only during implementation... because of the inadequacies of the underlying ideas." Brooks (1975) goes on to say that computer programming allows a programmer to build from thought, where concepts are flexible and we expect few difficulties in implementation. This persistent optimism, where we expect few difficulties, is unjustified given that ideas are faulty and thus, introduce risk and uncertainty.

To address risk associated with program evaluations and software development, metrics have been developed to support program management and program planning. In today's programs, the development of software is a significant component of the development effort. Therefore, the discussion of software metrics along with program metrics is discussed next.

2.6.1 Program Metrics

It is also believed that even though succinct requirements may exist for the planning of a program, the usage of conventional estimation techniques may not always give the best result in estimation and planning. There is no clear consensus on how to estimate and plan, taking into account that language is full of vague expressions, ambiguities and uncertainty even when assumptions are written down.

However, when the activity times in the project are deterministic and known (Taylor III, 2007), the critical path method (CPM) has been demonstrated to provide sufficient insight into managing projects (A. Kumar & Kaur, 2010). The purpose of CPM is to identify critical activities on the critical path so that resources may be allocated to these activities to reduce the program task execution time. CPM can provide adequate insight into the modifications of software, if the complexity of the modification or development is not high. Conditions of high complexity appear to be more common where the project scheduling problem is to determine the scheduling of tasks and allocating resources to balance the total cost and the completion time. This project considers a type of project scheduling problem with uncertain activity duration times, fluid milestones and resource deficiencies that have caused schedule delays and program crises.

2.6.2 Software Metrics

One major concern for the program under study is the management of software development. Academic theses and whole books have been written on the simple question, "How do I improve software development, planning and implementation?"

To answer this question, documentation utilized by the US Air Force indicates that driving factors in DoD software development include cost and schedule (Smith, 2003). In software development programs, what drives cost and schedule? McCabe (1976) identifies complexity as a driver in software development efforts, which include development testability and maintainability. Complexity depends on the decision structure of a program, which in turn drives cost and schedule estimates. Because cost is one of the key components of any developmental program, especially software development, cost must be reviewed carefully as part of the program planning processes along with detailed assumptions for schedule development.

Software metrics, according to Grey and MacDonell (1997), are measurements of the software development process and product that can be used as variables (both dependent and independent) in models for project management. The most common types of these models are those used for predicting the development effort for a software system based on size, complexity, developer characteristics, and other metrics. In software, the size of the program is the most significant driver of cost and schedule (Smith, 2003). Additionally, these other factors impact cost and schedule to varying degrees and must be taken into account. The most common application of software metrics (Grey & MacDonell, 1997) is to develop models that predict the effort required to complete specific stages of a software system's development.

These factors, according to Smith (2003), indicate that some metrics are usually more qualitative in nature and address the development and operational environments. Most software cost estimating models use these factors to determine environmental and complexity factors which are, in turn, used in computations to calculate effort and cost, such that this information should be integrated into scheduling and duration analysis of program planning efforts.

Yahaya and Mohamad's work (2011), along with Krusko's (2004) work, are examples of responses to improve software development through the use of software and complexity metrics. Table 1 provides proscribed values for software development metrics derived from calculations of Krusko's thesis. It is this type of empirical input which may be useful for inclusion in this project especially during the evaluation and analysis of data.

Early in the program's lifecycle, especially in the planning stages, Yahaya and Mohamad (2011) believe that program management insight into program planning and estimation is abstract, vague and subjective. Gray and MacDonell (1997) indicate that problems exists with programs that use crisp statistical models in estimation.

Complexity Metrics			
Measure	Min-Value	Max-Value	Upper Limit
Cyclomatic complexity (measure of the number of decisions in control flow)	2	15	30
Maximum nesting of control structures	1	5	10
Estimated static path count	4	250	1000
Myer's Interval (an extension to the Cyclomatic Complexity metric)	1	10	20
Number of function calls	1	10	40
Estimated function coupling	1	150	300
Number of executable lines	1	70	200
Number of statements	100	700	1300

Table 1. Complexity Metrics Adapted from (Krusko, 2004, p. 50).

Program managers face difficulty in specifying the exact values for the estimations which are often used as inputs for planning. Program planners often use values that have been used on other programs. Thus, estimations are based on historical perspectives. This is a problem since, for many metrics, the actual value is never known with certainty until the project is completed and these historical estimates may not represent actual conditions at program completion.

Using such models demands a level of accuracy in prediction from project managers that is rarely possible early in the program life cycle; the very time that planning is crucial.

It is obvious that enhanced techniques are required to improve cost and scheduling planning and evaluations. Change is required to improve robustness and decision-making.

2.7 EXISTING PROGRAM CONDITIONS

In the program under study, program management tools are used at every level to organize tasks, track status, allocate responsibilities, and then plan and track program costs and resources. The following sections describe the current operational environment for the program under study. The following sections specifically describe the types of contracts used in large acquisition programs, contract performance, existing program management tools and subsequent data analysis functions.

2.7.1 Contracts

Machines communicate with each other through networks and therefore make billions of decisions per second due to consistent and standard communications. If it were not for the explicit standards developed for machine communications, the electronic version of this paper would not be possible. However, communication, in general, is an on-going struggle for humans. The same is true for acquisition programs in the Department of Defense, where the procurement of large-scale military systems requires explicit communication between the government and the vendor. These communications are defined along with associated regulations in the Federal Acquisition Regulations (FARs)(Defense Logistics Agency, 2011).

The FARs provide legislation and guidance for governmental procurements, and address specific processes for interaction between the vendor and the government. Program management issues still need to be addressed between the government and vendor program managers where verbal and electronic email communications are the main mechanism for exchanging information.

Even though contract specifications explain and define responsibilities, there still remains enough vagueness in areas of contracts that contract negotiations are of considerable importance to stakeholders. For the system vendor and government program manager, the prediction of contract effort is an extremely important activity when contract negotiations will determine the value and scope of a contract (NAVSEA SUPSHIP, 2011).

Cost and schedule estimates for contracts are developed early in a program's life cycle and frequently form the basis for contract negotiations (Grey & MacDonell, 1997). These estimates and resource allocation activities, even though potentially speculative, may be used throughout the entirety of a contract. For contract development efforts, estimation is vital and enables the vendor program manager to plan, monitor and control the subsequent development process.

The modeling and estimation of contract efforts are vitally important to the government program manager as well, in that operations may be planned around the delivery of a system. It is clear that an accurate and robust estimation and status model is desirable from all perspectives since the FARs provide explicit contract stipulations which must be adhered to upon contract award.

2.7.1.1 Federal Acquisition Regulations

When the government plans to procure services or products, many steps must be taken to ensure that preferences and biases are not introduced into the process and cause undue problems with contract awards. The Federal Acquisition Regulations (FARs) (Defense Logistics Agency, 2011) provide guidance and policy when the DoD procures large-scale military systems. The FARs provide specific guidance associated with the solicitations and types of contracts that are to be utilized in acquisition programs.

Solicitations are defined under the FARs Part 2(Defense Logistics Agency, 2011) as "offers" or "quotations" provided to the government. The solicitations are provided as responses to requests for quotations, invitations for bids, or requests for proposals. Requests for proposals (RFPs) are used in negotiated acquisitions to communicate government requirements to prospective contractors and to solicit proposals. RFPs for competitive acquisitions, at a minimum, describe:

- The government's requirements
- Anticipated terms and conditions that will apply to the contract
- Information required to be in the vendor's proposal, and
- Factors that will be used to evaluate the proposal and their relative importance.

These RFPs are used as a basis to determine if potential vendors exist and are able to produce a product that will meet the government's requirements. RFPs may also be used to help determine the type of contract that will be necessary to procure the services of the winning vendor.

FARs Part 16 define and specify contract types to be utilized in acquisition programs (Defense Logistics Agency, 2011). These contracts are generally grouped into two broad categories:

- Fixed-price contracts
- Cost-reimbursement contracts

The FARs specify contract types which range from firm-fixed price, in which the contractor has full responsibility for the performance costs and resulting profit (or loss), to cost-plus-fixed-fee, in which the contractor has minimal responsibility for the performance costs and the negotiated fee (profit) is fixed. While these two general types of contracts define the boundary conditions, for most acquisition programs, additional variations allowed contract specialist to tailor the contract. Between these endpoints, various incentive contracts exist in which the contractor's responsibility for the performance costs and the profit or fee incentives offered are tailored to the uncertainties involved during contract performance. The following sections describe the specific types of contracts used on the program, so that the reader may comprehend the implications of specifications and restrictions of a contract and address the potential aspects of contract performance.

2.7.1.2 Cost Reimbursable Contracts

Cost reimbursable contracts (Defense Logistics Agency, 2011) establish an estimate of the total cost of the program, and establish a fixed amount that the contractor may not exceed without governmental approval. Cost reimbursable contracts are used when uncertainties are involved in the performance of the acquisition. In the case where developmental efforts are necessary, such as in the procurement of large-scale systems, generally a cost plus type contract is utilized. These contracts are meant to help keep the basic cost of the contract to a minimum by providing incentives to the vendor.

2.7.1.3 Cost Plus Award Fee (CPAF) Contract

The cost plus award fee contract was utilized during the initial development of the systems by the original vendor. This contract was utilized where the system required developmental efforts. In the development of large-scale systems, generally a cost plus type contract is utilized. A cost plus contract is negotiated with provisional fees added to the contract price (Defense Logistics Agency, 2011). This provides a means of applying incentives in contracts which are not susceptible to finite measurements of performance necessary for structuring fixed price contracts. These incentives are meant to help keep the basic cost of the contract to a minimum. The incentives are generally inversely proportional to the cost of the contract. This relationship to the basic cost of the contract means that the vendor could acquire greater profits by holding down the basic cost associated with the contract.

2.7.1.4 Fixed Price Contracts

Fixed price contracts (Defense Logistics Agency, 2011) provide for a firm price for the government. A firm fixed priced contract provides for a price that is not subject to any adjustment on the basis of the contractor's cost experience in performing the contract. Thus, the fixed price contract places more cost responsibility on the contractor than on the government, and makes profit a function of the contractor's ability to manage cost.

2.7.1.5 Fixed Price Incentive Fee (FPIF) Contracts

After prototype systems development and identification of prime item development specifications, a second vendor was chosen to perform the full rate production of the RFEBC systems. The fixed price incentive fee contract was utilized in this phase of the acquisition process. This is a common practice when acquisition programs reach the production phase. The fixed price contract places maximum risk and full responsibility on the contractor for all costs and resulting profits or losses. The FPIF provides (Defense Logistics Agency, 2011) maximum incentive for the contractor to control costs and perform effectively and imposes a minimum administrative burden (i.e. reduced reporting requirements) upon contracting parties. Thus the fixed price contract places more cost responsibility on the contractor than on the government and makes profit a function of the contractor's ability to manage the program. Conditions in the contract allow the government to incentivize the vendor to meet the constraints of cost, schedule and scope.

2.7.1.6 Contract performance

The issues of communication and comprehension of decision making strategies are at the core of this project. As discussed earlier, the vendor chosen to perform the full rate production of the RFEBC systems received a FPIF contract for a specified number of RFEBC systems. A FPIF contract effectively places constraints on the company to ensure that the systems are delivered with a specific set of attributes and capabilities, with a set delivery date and a set cost.

This type of contract effectively locks the company into a condition where there are no releases should cost growth and/or schedule delay occur in the program. This type of contract is in contrast with the prior contract which was CPAF in nature where the cost, schedule and attributes & capabilities were flexible.

2.8 PROGRAM ENVIRONMENT

Even though the vendor was solely responsible for delivery of the RFEBC systems at the end of the contract, stipulations in the contract required the vendor to utilize standard program reporting mechanisms. Earned value management data, critical path analysis and resource utilization evaluations were required to be delivered on a monthly basis to ensure that the program was progressing. This data has been sanitized and normalized such that it can be used in this project. The following sections describe specifics for cost management and technical management of the program. The sections specifically discuss the application of earned value management, which is mandated by the Department of Defense, and applications utilized in technical management of the program.

2.8.1 Cost Management

Producing profit in any commercial company is a prime objective. To accomplish these objectives, companies require visibility into program management efforts. Many companies use standardized approaches and applications to accomplish these goals. Similarily, government contracts for large-scale acquisition programs mandate that cost management tools be utilized to provide insight into the progress of a program.

2.8.1.1 Earned Value Management

Earned Value Management (EVM) is a project management control tool allowing visibility into performance and progress for major programs. The objective for government and vendor program managers utilizing EVM is effective management control of contract performance risk and to obtain early indicators of cost, performance, and schedule results. The definitions used by governmental acquisition agents have been defined by the Federal CIO Council (2005). EVM encourages contractors to use effective internal cost and schedule management control systems, and provides the program manager with timely and consistent cost, schedule and progress data. The implementation of an Earned Value Management

System (EVMS) ensures that cost and schedule aspects of a contract are integrated where actual progress of the program can be monitored. Why use EVM as a data source in this project? The legislation to use metrics dates back almost 20 years. The following legislation requires that metrics and EVMS be utilized for specific acquisition programs:

- Government Performance and Results Act of 1993 – Mandates the use of metrics.
- Federal Acquisition Streamlining Act of 1994 – Requires agencies to achieve ninety percent of the cost and schedule goals for major and non-major acquisition programs.
- Clinger-Cohen Act of 1996 – Requires establishment of the processes for executive agencies to analyze, track, and evaluate risks and results.

Additionally, the Office of Management & Budget (OMB) policies stipulate standards for planning, budgeting and acquisition of capital assets. These policies include:

- OMB Circular A-11 (Part 7, Planning, Budgeting, Acquisition & Management of Capital Asset) – This document outlines processes for program management earned value techniques.
- OMB Memorandum M-05-23, "Improving Information Technology (IT) Project Planning and Execution" – This document provides guidance and assists agencies in monitoring program execution and implementation of EVMS.

OMB Circular A-11(Federal CIO Council, 2005) states that where developmental effort is necessary, EVMS is mandatory for parts of the program.

Furthermore, agencies may identify additional tailoring criteria for defining projects for which EVMS is required. Such classifications may be based on program criteria including:

- Level of management visibility
- Level of development/modernization/enhancement
- Duration of development phase
- Level of risk

Even with tailoring, the objective remains to achieve effective management control of contract performance risk and to obtain early indicators of expected cost, performance, and schedule results.

EVM, according to other governmental agencies (NAVSEA SUPSHIP, 2011), has proven its value over many years. Effective and appropriate implementation and application by vendors ensures that they possess and use adequate program management systems that integrate cost, schedule, and technical performance.

2.8.1.2 EVM Industry Performance Measurement Guidelines

Earned value is a value-added metric (Atlantic Management Ctr. Incorporated, 2005; Federal CIO Council, 2005) that is computed on the basis of the resources consumed, then compared to the accomplished work scope to provide a direct measurement of the quantity of work accomplished. Earned value analysis evaluates program performance and facilitates problem identification for more effective management action. It also permits segregating schedule and cost problems for improved visibility into program performance. Continued earned value analysis permits analysis of corrective decisions to assess effectiveness. To achieve this end, legislation, standards and guidelines cited above have been implemented by the DoD to facilitate EVM participation in programs for large-scale military system procurements. To ensure standardization in industry, relevant standards include the American National Standards Institute/Electronic Industries Association (ANSI/EIA) Earned Value Management System Standard 748-1998 (NAVSEA SUPSHIP, 2011, p. 10). This standard is used in industry processes for EVMS, which include integration of program scope, schedule and cost objectives, establishment of a baseline plan for accomplishment of program objectives, and use of earned value techniques for performance measurement during the execution of the program.

Industry standard ANSI/EIA Standard 748 (NAVSEA SUPSHIP, 2011) provides for an overall structure for an integrated cost, schedule and performance measurement system. The structure consists of thirty-two criteria organized into five high-level categories which include:

- Organization,
- Planning, Scheduling and Budgeting,
- Accounting Considerations,
- Analysis and Management Reports, and
- Revisions and Data Maintenance.

The EVMS guidelines and criteria (Defense Logistics Agency, 2011; NAVSEA SUPSHIP, 2011) were established on the premise that the government cannot impose a single EVMS for all contractors due to variations in organizations, products, and working relationships. The guidelines establish a framework within which an adequate integrated cost, schedule, and technical management system fits. The EVMS guidelines are not prescriptive, but simply describe the desired outcomes of integrated performance management.

EVMS guidelines (Defense Logistics Agency, 2011) are intended to be objective and applicable to large, potentially risky programs. The purpose of the guidelines is to provide the contractor and the government with accurate data to monitor execution of the program and to preclude the imposition of specific cost and schedule management control systems by providing uniform evaluation guidelines to ensure contractor cost and schedule management control systems are adequate and provide a basis for responsible decision making. This is accomplished by requiring that contractors' internal management control systems produce data that:

- Indicates work progress
- Properly relates cost, schedule, and technical accomplishment
- Provide DoD managers with information at a practical level of summarization
- Encourage DoD contractors to adopt management control systems and procedures that are most effective in meeting requirements and controlling contract performance.

To facilitate understanding and communication of EVMS, the basic requirements for effective implementation of an EVMS include:

- Defining and organizing all work necessary to complete the project, typically through the use of a Work Breakdown Structure.

- Planning the work elements of the WBS to determine the time and estimated costs required to perform the work.
- Developing a project network that integrates the scope of work, schedule, and cost objectives into a time-phased baseline plan that spans the duration of the project.
- Defining "earning rules" for measuring the accomplishment of the WBS work elements. (A variety of different earning rules may be applied within the same EVMS based on the nature of the work.)
- Periodically determining the program's earned value by applying the earning rules to each work element and summing the earned value of all work.
- Comparing the earned value against the baseline plan to determine cost and schedule variances.
- Analyzing significant variances to determine their cause, to forecast impact, and to determine appropriate corrective action.

These basic requirements must be explicitly defined and adhered to consistently during program execution, otherwise contract deviations may occur and cause potential situations where cost and schedule issues are not identified and corrected. The evaluation of EVM data assists the program manager to identify these potential issues and execute plans to reduce risk. Specifics for EVM data evaluation are included in the following section.

2.8.1.3 EVM Analysis and Management Reports

EVM reporting requires tools to generate project summary information. Summary information must include estimates, actual, schedule and cost variances, such as EVM calculations (Kerzner, 2006):

- Budget Cost of Work Scheduled (BCWS),

- Budgeted Cost of Work Performed (BCWP),
- Actual Cost of Work Performed (ACWP),
- Cost Performance Index (CPI) and
- Schedule Performance Index (SPI).

The estimates and variances above are used to generate earned value reports(Centeno-Gomez et al., 2001). The DoD (NAVSEA SUPSHIP, 2011) recognizes that EVM data should provide an adequate basis for responsible decision-making by both contractor management and DoD personnel by requiring that contractors' internal management control systems produce data that:

- Indicate work progress,
- Relate cost, schedule, and technical accomplishment , and
- Provide DoD managers with information at a practical level of summarization

DLA (Defense Logistics Agency, 2011) recommends that corrective action plans for schedule and costs deviations be in place at the start of any program and, at least on a monthly basis, generate the following information at the control account level for management control using actual cost data from, or reconcilable with, the accounting system and schedule progress data from the PMSP:

- Comparison of the amount of planned budget and the amount of budget earned for work accomplished. This comparison provides the schedule variance.
- Comparison of the amount of the budget earned the actual direct costs for the same work. This comparison provides the cost variance.
- Identify, significant differences between both planned and actual schedule performance and planned and actual cost performance, and provide the reasons for the variances in the detail needed by program management.

- Identify budgeted and applied (or actual) indirect costs at the level and frequency needed by management for effective control, along with the reasons for any significant variances.
- Summarize the data elements and associated variances through the program organization and/or work breakdown structure to support management needs and any customer reporting specified in the contract.
- Implement managerial actions taken as the result of earned value information.

Given that the vendor reports variances outside of agreed-to levels, the vendor should develop revised estimates of cost at completion based on performance to date, commitment values for material, and estimates of future conditions. This information should then be compared to the performance measurement baseline to identify variances at program completion. Contract deliverables from the vendor for this program appear to meet the requirements listed above.

2.8.2 EVM Data Evaluation

The concept of value or, in this case, a measure of quality in earned value management figures prominently in this research effort. One of the criticisms of EVM is that the notion of value and the measure of quality is subjective and thus, open to interpretation when reporting earned value status. The following sections address the issues associated with value and whether or not this is a fair critique with respect to this project.

2.8.2.1 EVM Exploitation

Does EVM actually encourage program managers to make bad decisions? Can a simple scoring system designed to track project performance actually contribute to major project failure? Yates (2005) asks these questions and discusses the use of earned value management.

In his discussion, Yates (2005) addresses the tendency of program managers to exploit deficiencies of EVM and comes to the conclusion that "earned value does not promote poor quality—it is just blind to quality." More importantly, Yates (2005) contains two observations that are very important to this research effort; EVM assumes that quality for every task is equal and absolute, and EVM assumes task quality will meet or exceed the required level for the project. However, Yates (2005) most important observation is that these assumptions are necessary in order for earned value metrics to be used as a common yardstick. Given that these views were expressed in 2005, it is interesting that the governmental reports followed this article years later.

2.8.2.2 Recognition of EVM Exploitation

The following references cite issues with respect to tailoring and standardization with EVM practices and implementation in large technically complex government and Department of Defense programs.

The Under Secretary of Defense (USD), Acquisition, Technology and Logistics (AT&L) (USD AT&L, 2007), published the following excerpt in a memorandum discussing earned value management on 3 July 2007.

> "Despite the proven value of EVM, we are not maximizing its benefits in managing defense programs. ... unfavorable findings from recent audits further indicate that EVM is not serving its intended function in the internal control process."

Work breakdown structures (WBS), an important input into EVM and integrated management systems, are used to calculate metrics for program progress. On , 9 January 2009 the Deputy Under Secretary of Defense (DUSD) AT&L (2009) published the following findings on the implementation of scheduling product WBSs. The DUSD AT&L indicated that lack of WBS standardization has resulted in significant problems, which include the impediment of effective program management practices, difficulty in reconciling data submissions, and inaccurate data collection and analysis.

Additional findings in audits for the Director of Acquisition Resources and Analysis (ARA) (2008), published on 27 August 2008 followed the Under Secretary report. The Director for ARA and the Defense Contracts Management Agency identified EVM implementation issues on DoD contracts where, solicitations failed to include applicable EVM requirements, and contracts include inappropriate tailoring of data item descriptions. These issues caused deficiencies in contract performance reporting and in integrated master schedule data where contract requirements were not consistent with EVM policy and EVM guidelines.

In an EVM utilization report to Congress (Office of the Deputy Under Secretary of Defense, 2009) indicates that EVM faces many problems. These include unrealistic cost estimates, overly aggressive delivery schedules, and establishment of unrealistic performance measurement baselines.

Even with the guidelines and the guidance repository that the DoD has developed, can governmental and DoD program managers prevent the exploitation of EVM when the vendor can pad the schedule, move problem tasks to the end of the program, inflate task completion percentages, and re-baseline the schedule to improve EVM metrics? Because of the lack of definition and resulting value gap in the EVM standard, there is no assurance the reported earned value is based on realistic progress metrics.

2.8.2.3 Mitigating EVM Exploitation

The following steps may be taken to mitigate this concern and enhance methods through which EVM negative variances are resolved in organizations that rely on earned value. To improve the utility of earned values management, program managers should ensure that the output from earned value management includes a measurement of product quality and technical maturity, instead of just the quantity of work accomplished. EVM enhancements should be required to provide precise, quantifiable measures of progress.

In recognition of these issues, the DUSD report (Office of the Deputy Under Secretary of Defense, 2009) discusses areas for improvement which include:

- Publishing a DoD Guide to Analysis of Earned Value Management and Cost Data
- Updating the DoD Earned Value Management Implementation Guide,

- Improving compliance and requirements for delivery of timely, complete, and accurate EVM data,
- Continuing development of EVM diagnostics tools to apply EVM information in acquisition decision-making.

Reference material developed by the Department of Defense (Defense Accusition University, 2012b) for evaluation of earned values management such as the DoD Earned Value Management Implementation Guide, the Defense Acquisition University (DAU) EVM "Gold Card", and the Interpretive Guide and Checklist, also known as the "Bowman" Guide from 1991, provide specific interpretation of the current 32 EVM criteria.

These documents provide guidance for understanding EVMS concepts by describing objective guidelines for EVM systems, and providing guidance in interpreting those guidelines for use on government contracts and programs. These guides contain descriptions of procedures and processes for specifying, evaluating, and implementing EVM systems. They also contain instructions and tailoring guidance for applying EVM requirements to contracts, an introduction to analyzing performance, baseline review and maintenance, and other post award activities. However, as stated in the report to Congress (2009) the Deputy Under Secretary of Defense AT&L recognizes the need to continue development of EVM diagnostics tools to apply appropriate EVM information in acquisition decision-making.

Even with the variances, indices and metrics associated with EVM, EVM can be manipulated such that the efficiency indicators do not represent the true health of the program. Quality, a measure of value, is not used in any calculations to report EVM program status. This situation directs this research project to address EVM enhancement through the derivation of quality heuristics.

2.8.2.4 EVM Cost Reporting Elements

Tools that are in use in the program provide excellent insight into the management of cost. The reporting of EVM data, which includes the elements described above for the management of cost, were reviewed each month by government cost analysts. The analysis and reporting of this data are used to ensure that:

- Budget at Completion (BAC) is greater than Cumulative Budget Cost of Work Scheduled (BCWS) and that it is equal to the negotiated cost plus the estimated cost of authorized yet to be priced work
- Contract Budget Base (CBB) tracks to the Negotiated Contract Cost (NCC)
- Actual Cost of Work Performed (ACWP) is not greater than Estimate at Completion (EAC) or BAC
- Actual performance does not occur without associated budgeted performance (ACWP without BCWP)
- Identify variances exceeding thresholds that require analysis contained in the CDRL
- Compare prior period and current period BCWS differences and address differences.

The application is utilized on this program, not only as a management tool but as a reporting tool to analyze vendor supplied data. With a FPIF contract, the government is not responsible for cost deviations experienced by the vendor.

However, it is in the government's interest to be aware of cost variances and potential overruns of the contract. Initially, contract deliverables from the vendor for this program appear to meet the requirements listed above. On further analysis, there appears to be a significant disconnect between budget planning and EVM analysis.

The crisis that is faced by the government if a vendor overruns the negotiated price of the contract is that the vendor may default on the contract. This leaves the government in a situation where all funds have been executed and no product is delivered. Therefore, an understanding of EVM basics is required and is discussed in the following sections.

2.8.3 EVM Basics

Before discussing enhancements to EVM, one must understand the basis for reporting EVM. The following terminology, variances, indices and rules are currently used to report program status. Therefore, categorization of the basics of EVM reporting is discussed next. The terminology, variances, indices and examples of earning rules are outlined below in Table 2.

EVM Performance	
ACWP	Actual Cost of Work Performed - Cost of work accomplished
BAC	Budget At Completion -Total budget for contract
BCWP	Budgeted Cost of Work Performed - Value of work accomplished
BCWS	Budgeted Cost of Work Scheduled - Value of work planned to be accomplished
EAC	Estimate At Completion Estimate – Estimate of total cost for contract
PMB	Performance Measurement Baseline - Contract time-phased budget plan
TAB	Total Allocated Budget - Sum of all budgets for work on contract
TCPI	To Complete Performance Index - Efficiency needed from "time now" to achieve an EAC
EVM Variances	
Cost Variance - CV	BCWP – ACWP CV% = CV / BCWP x 100%
Schedule Variance SV	BCWP – BCWS SV% = SV / BCWS x 100%
Variance at Completion VAC	BAC – EAC
EVM Indices	
Cost Efficiency - CPI	BCWP / ACWP
Estimate At Completion - EAC	Actuals to Date + (Remaining Work / Efficiency Factor)
EACCost	ACWP + [(BAC – BCWP) / CPI] = BAC / CPI
EACSked	ACWP + [(BAC – BCWP) / SPI]
Schedule Efficiency SPI	BCWP / BCWS
(>1 is favorable; <1 is unfavorable)	

Table 2. EVM Terminology

Additionally, to use EVM, one must have a measure to evaluate completion of tasks and milestones. These are known as earning rules. A discussion of all the earning rules is beyond the scope of this paper. However, a variety of different earning rules may be applied within the same EVM reporting system, or a single earning rule may be employed to all tasks and milestones. One of the easiest to apply is the 50/50 earning rule. Using the 50/50 rule, 50% credit is earned when an element of work is started and the remaining 50% is earned upon completion. In this instance, any given milestone is considered 50% complete from the first day of the task until the last day. This earning rule provides no visibility into the actual work that is being executed in the milestone tasks. There is no measure of progress or quality when using this earning rule. If multiple earning rules are used in a program, unless specified for each milestone, one cannot know if progress is being made or even how progress is measured.

2.8.4 Technical Management

How long will a programming job take? How much effort is required? How does one estimate task durations? How does one estimate resources? Academic theses and whole books have been written on the simple questions above. Parsons' (2003) work is an example of answering the question of how to improve program development through the categorization of variables which could be monitored to evaluate a program's progress. Fowlkes, Neville, Hoffman and Zachary (2007) discuss issues of designing complex systems, and work by Ding and Zhang (2010) provides a mathematical approach to addressing uncertainty in program scheduling. However, before discussing the advanced work of these and other authors, a foundation must be developed which utilizes an historical perspective.

2.8.4.1 Schedule Development and Estimation of Resources

Since the 1970s, many companies and government agencies have been concerned with schedule delays and cost overruns in software development efforts. Software has been an ever-growing segment of systems development and has experienced significant problems. Many considered scheduling problems to be the source of software development cost overruns. Therefore, scheduling was a focus for many authors. One of these authors included Frederick P. Brooks, the author of *The Mythical Man-Month*. When developing a schedule, especially for a software development effort, Brooks (1975) reiterates that one does not estimate the entire task by estimating the coding portion and then applying some factor. Coding is only about one sixth of the development effort and errors in this estimate or in the estimation ratios could lead to ridiculous results. Figure 4 below approximates data from a study performed by Nanus and Farr (1964).

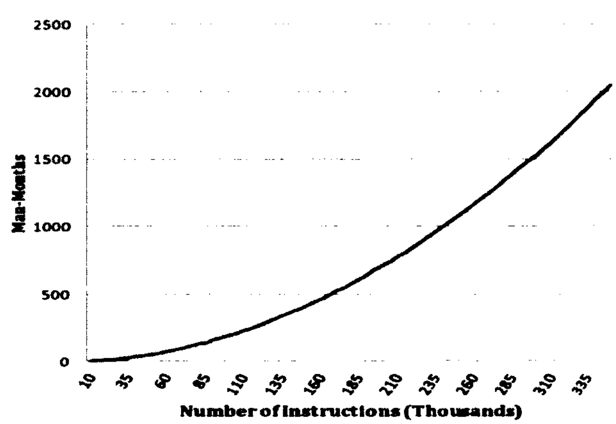

Figure 4. Nanus and Farr's Data 1964 Study Adapted from (Brooks, 1975, p. 89).

This study at Systems Development Corporation indicated that to calculate effort, the following function, which is exponential, provides a basis for programming effort versus program size estimates:

$$\text{Effort} = (\text{constant}) \times (\text{number of instructions})^{1.5} \qquad (2.1)$$

While the simplistic function above is related to the number of assembly instructions in programming in the 1970s, additional functions and applications are used today to estimate programming task effort. The reason to address this issue is to highlight the failure to accurately estimate levels of effort for development of software today.

Applications such as COCOMO provide "enhanced" estimation techniques. However, if the inputs into such applications are overly optimistic, then the output will also be overly optimistic, causing tasks to overrun task durations and cause schedule delays. A survey by Molokken and Jorgensen (2003) finds that as many as eighty percent of software programs experience schedule delays and that estimation methods used most frequently indicate that there is no evidence that formal estimation models lead to more accurate estimates. An additional survey finding indicates that empirical data does not exist to provide analyses of the reasons for effort and schedule overruns.

These survey findings support the supposition that inadequately estimated inputs produce inaccurate outputs, thus leading to the conditions experienced in the program that is the subject of this project.

Jorgenson and Grimstad's (2011) work supports the position reported by Brooks (1975), where Charles Portman, a manager of the ICL software division for the Computer Equipment Organization, relates a situation in which program teams missed schedules by approximately fifty percent. Information gathered during this investigation showed that schedule estimating errors accounted for the fact that teams realized only fifty percent of a work week where actual programming and debugging time were reduced by extraneous activities including machine downtime, higher priority short unrelated jobs, meetings, paperwork, company business, sickness, and personal time. Therefore, estimates were made on unrealistic assumptions about the number of technical work hours per man year (See Figure 5). In addition to these issues faced by software developers, a much longer list by Kerzner (2006, p. 281) shows the "time robbers" for a program manager where good faith estimates in time management may be reduced to uninformed guesses.

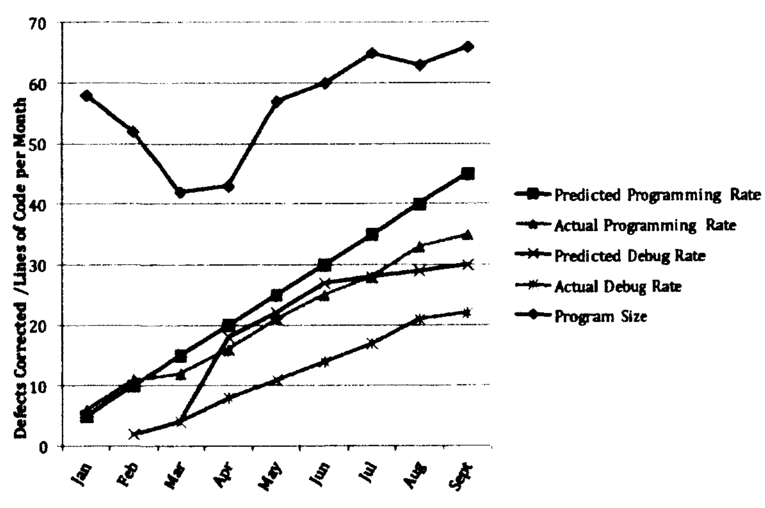

Figure 5. Harr's Data Adapted from (Brooks, 1975, p. 92).

While the measurement units utilized in the metrics above are archaic, given the advanced programming tools used today to develop software, errors in the development of assumptions for estimates of task duration, work allocation and resource allocation still are program management issues which should be measured and addressed.

2.8.4.2 Schedule Development Precursors

Parsons' (2003) evaluation indicates that the identification of program variables will allow program managers to identify areas of risk and plan for potential program crises. In software estimation, Brooks (1975) indicates that there is a need to develop and publicize productivity figures, defect incidence figures, estimation rules, additional interactions and impact analysis (Goradia, 1993). This is especially true in the development of schedules where the prediction of defects in a product have caused schedule delays. Many programs have failed due to traditional approaches in the prediction of defects (Fenton et al., 2007) and inadequate scheduling estimation methods.

Brooks (1975) states that programs which utilize improper scheduling to meet a specific delivery date, or implement schedules and estimates that are derived through non-quantitative methods are prone to failure. Therefore, the ability to provide realistic estimations in the development of schedules is an essential aspect of the management of programs and is of significance in this project.

The Department of Navy recommends for the development of schedules (Atlantic Management Ctr. Incorporated, 2005) that activities occur as precursors to developing schedules. These scheduling development activities include identifying specific activities to produce program deliverables, identifying and documenting relationships between schedule activities and milestones, estimating resources and estimating durations to complete schedule activities.

By addressing schedule activities and task sequences to estimate task durations, resource requirements and schedule constraints; the following inputs, tools, techniques and outputs can be defined for each of these sequences of events. This effort has been completed by Atlantic Management Center (2005) and includes efforts (See Table 3) such as activity identification and sequencing, resource estimating and duration estimating where each of these activities should precede schedule development.

Given the advancement of estimation methodologies that have been developed over the past half century, scheduling estimation techniques do not appear to have improved the accuracy between predicted and actual rates of task completion.

While the above examples provide one small window to software development in the 1960s and 1970s, data set metrics utilized at that time may prove useful when comparing similar efforts and products that are used currently and have been applied to the program as tools to monitor program management efforts.

Inputs	***Tools and Techniques To Develop Outputs***	***Outputs***
	Identification of Tasks and Activities	
Work breakdown structure, scope statement, historical information, constraints, assumptions, expert judgment	Decomposition, templates	Activity list, supporting detail, work breakdown structure updates
	Activity and Resource Estimating	
Enterprise environmental factors, organizational process assets, activity list, activity attributes, resource availability, project management plan	Expert judgment, alternatives analysis, published estimating data, project management software, bottom-up estimating	Activity resource requirements, activity attributes and updates, resource breakdown structure, resource calendar updates, requested changes.
	Estimation of Activity Duration	
Activity lists, content, dependencies, assumptions, resource requirements, resource capabilities, historical information, identified risks	Analogous estimating, quantitatively based durations, expert judgment, detailed estimating, reserve time	Activity duration estimates, basis of estimates, activity list updates
	Sequencing of Activities	
Activity list, product description, mandatory dependencies, discretionary dependencies, external dependencies, milestones	Precedence diagramming method, conditional diagramming methods, network templates	Project network diagrams, activity list updates

Table 3. Schedule Predecessor Activities Adapted from (Atlantic Management Ctr. Incorporated, 2005).

2.8.4.3 Current Schedule Analysis Applications

Software applications used by the sponsor allow schedule analysts to present schedule metrics any way that a task may be flagged in a scheduling tool, such as MS Project, which is used in the program under study. Schedule metrics can be broken into the various lists and filtered for specific information that could lead to identifying problem areas in the schedule evaluation. As an example, it is beneficial for the analyst to know who is responsible for an increasing trend of missed tasks. The program office may find value since program managers can assess schedule metrics each month to determine if specific areas need further investigation. Additionally, action item lists help to focus the attention of program managers, technical leads, and the schedule analyst on the schedule health and schedule performance issues that might be detrimental to program success. To support the evaluation of the conditions above, specific functions provided in the schedule analysis application include:

1. <u>IPT Schedule Listing:</u> This report is the schedule in table format. Most, if not all, of the schedule fields that a technical lead or manager needs are contained in this table. This is a more universally accessible view that can be sorted and filtered as needed.
2. <u>Missing Baseline Date:</u> This is an action item list that specifies each task that is missing either a Baseline Start or a Baseline Finish date. It is important for managers to know that the work has been base-lined so that performance can be measured and know that the baseline configuration is being implemented.

3. Improper Status: This is an action item list primarily for the schedule analyst to send back to the contractor to ensure that the tasks are reflecting the accurate forecast and actual dates on the tasks.
4. Missing Predecessors or Successors: This is an action item list that will specify each task that is missing either a predecessor or a successor. In a networked schedule, every task should have both a predecessor and successor except the first and last task of a project. When this logic is missing, there is a higher chance that the work is not detailed in the manner in which it is to be accomplished, the critical path may be incorrect, or forecast dates are not accurate. While this will not determine whether the predecessors and successors are correct, it will highlight those that must be addressed to complete the schedule network.
5. Check Successors: This is an action item list that focuses on the validity of the successor relationships. The application uses excessive total float as a litmus test to determine which tasks should be investigated further.
6. Constraints: This is an action item list of all the tasks with constraints in the schedule. Whether these constraints are restrictive in nature or flexible, they should be evaluated by the technical lead. Constraints or deadlines can have a significant impact on the schedules ability to move freely based on logic or the accuracy of float values (criticality of tasks). It is important that they are applied only when they help to accurately model the way the work will be accomplished and not to artificially set critical path or improperly control other metrics.
7. High Duration: This is an action item list that points out any tasks with durations greater than two calendar months. Human nature is to be optimistic and to procrastinate. Thus, when status is reported, a manager of the task will be less likely to admit to a later forecast finish if a majority of the task duration is remaining.
8. Delinquent Starts: This is an action item list that notifies the analyst of tasks that have not started by the status date. The cause of these delinquent starts

may be preceding tasks that have not been completed or that attention of resources is focused elsewhere. It is important that these tasks are reviewed to ensure that the delay in starting these tasks will not be detrimental to the program.

9. Near Critical Delinquent Starts: This is an action item list that notifies the technical lead or analyst of those near-critical tasks that have not started by the status date. Starting these tasks should be the priority since any more delay to them would also delay key milestones.
10. Delinquent Finishes: This is an action item list that notifies the technical lead or analyst of those tasks that have not finished by the status date. The cause of these delinquent finishes is usually related to challenges with each task.
11. Near Critical Delinquent Finishes: This is an action item list that notifies the technical lead or analyst of those near-critical tasks that have not by the status date. Completing these tasks should be the priority among the other delinquent tasks since any more delay to them would also delay key milestones.
12. Near Critical Tasks: This is an action item list that highlights all the tasks in the schedule element that are close to being on the critical path.
13. Critical Tasks: This is an action item list that highlights the critical items in the schedule. Any delay in these tasks will cause a corresponding delay to the target milestone. It is imperative that the analyst, technical lead and program manager review this listing following each status of the schedule.
14. Tasks that Need to Regain Baseline: This is an action item list that highlights the tasks that either have started, or should have started according to the baseline plan, and are projected to finish late. In simple terms, they have some work to do to regain the baseline plan. The number of days associated with this is a helpful measure of the bow-wave effect on the schedule and may be most effectively used at the start of a program.

The ability to navigate through a schedule or associate a task with program reference documents is critically important. The above capabilities are used to aid the analyst and enhance the information so the schedule acts as a planning / execution tool and performance measurement indicator. The application products described above provide exceptional tools for schedule evaluations so the program manager can make informed decisions. There are other indicators that should be included for evaluation of the health of a schedule, and these include:

1. Ensuring that each task has work hours associated with it.
2. Ensuring that the task duration estimates correspond to the levels of effort required to complete the work, (i.e. resource allocation matches the amount of work expected during the execution of the task).
3. Ensuring the status of work completed matches the level of execution expected at the date that status is provided (i.e. resources are actually applied to the tasks where the status indicates progress). This may require that resource allocation measures be applied on a task by task basis. Resources (team members) should be charging against the actual work tasks where effort is expended.

2.9 META-HEURISTICS

How can meta-heuristics be applied to facilitate improving decision-making? Meta-heuristics are strategies, according to Paolucci (2006) and Yaghini (2009), which may be used to guide the exploration of a solution space where an iterative generation process guides a subordinate heuristic by combining different concepts for exploring and exploiting the search space in order to find better solutions. In the book written by Dreo, Siarry, Petrowski & Tillard (2006), a meta-heuristic is defined as a set of algorithmic concepts that can be used to develop heuristic methods applicable to a wide set of different problems. These definitions will be used to address the potential solution space in this project.

2.9.1 Meta-heuristic Implementation

The implementation of methods identified as meta-heuristics have come to be recognized for solving many complex problems which are combinatorial in nature. These methods, identified as heuristic algorithms by Paolucci (2006), are algorithms that solve an optimization problem by means of sensible rules to find a feasible solution which may not be the most optimal solution. For the purpose of this project, this process may be acceptable given that a supreme optimal solution is not feasible or definable.

Meta-heuristics, in addition to standard evaluation models, may be used to improve the outcomes associated with problems in program management. Researchers such as Ólafsson (2006), Paolucci (2006), and Yaghini (2009) believe that meta-heuristics are one of the most practical approaches to modeling where specific methods are designed for combinatorial optimization in multi-criteria decision making. Meta-heuristics (Ólafsson, 2006; Yaghini, 2009) are designed to tackle complex optimization problems where other optimization methods have failed. These methods have come to be recognized as one of the most practical approaches for solving many complex problems. Utilizing strategies identified during the literature review, the author has developed strategies so heuristics and meta-heuristics may be implemented to provide additional data so that decision-making confidence in program management decisions can be increased. To support the implementation of meta-heuristics, the topics of fuzzy logic, fuzzy failure modes effects analysis, fuzzy clustering and fuzzy Markov systems analysis are discussed below.

2.9.2 Fuzzy Logic

Fuzzy set generation is a complement to traditional set theory (Singpurwalla & Booker, 2004). A number of attributes of the fuzzy sets and methods provide a means for addressing issues in the "gray" areas of technical data analysis where uncertainty and complexity require additional consideration so these characteristics do not produce a type II or III error. Fuzzy methods and algorithms have been around since fuzzy set principles were identified by Zadeh (1965) and amplified by Mamdani (1977) and Takagi and Sugeno (1985). These methods have recently gained exposure (Senglaub & Bahill, 1995), principally in the areas of process and control engineering. It is the ability to deal with linguistic artifacts and uncertainty that have led other authors (Bezdek, 1993; Buckley & Eslami, 2002; Chai, Jia, & Zhang, 2009; Cominetti et al., 2010; Gaonkar, Amonkar, Sakhardande, & Kamat 2011; Guiffrida & Nagi, 1991; Izakian, Abraham, & Snášel, 2009; Jantzen, 1998; Karaboga & Ozturk, 2010; Klingenberg & Ribeiro, 2011; A. Kumar & Kaur, 2010) to further exploration and use of fuzzy logic.

Zadeh (1998) describes a fuzzy algorithm as an ordered set of fuzzy instructions that upon execution yield an approximate solution to a given problem. Fuzzy algorithms follow the premise just as non-fuzzy crisp algorithms, that an algorithm is usually expected to be capable of providing an approximate solution to any problem in a specified class of problems, rather than to a single problem.

Guiffrida and Nagi's (1991) paper provides a survey of the application of fuzzy set theory in production management research, with a review of 73 journal articles and nine books. Kumar and Kaur (2010) discussed the implications of technical data analysis, schedule development, schedule uncertainty and critical path analysis in a fuzzy environment. Kumar, Narula and Ahmed (2010) identify techniques based on fuzzy inference which have been proposed to explain the behavior of an unknown system for which only a set of input and output data is available. The fuzzy modeling, approach according to Kumar, et al. (2010), provides for system identification from numerical data which have distinguishing features, in that complex nonlinear systems can be expressed linguistically using fuzzy inference rules and membership functions.

This work is important to this project since the inputs to the program management tools are schedule and budget estimates and effort produced by the vendor. These inputs produce outputs measured by EVM as cost and schedule variances where there is little visibility into the transformation, resulting in uncertainty in the government's review of the issues. This potentially leads to the situation where a crisis may occur and the reporting of the crisis does not occur for many weeks, reducing the possible responses by the government.

In the case of this project, a problem exists where there is a risk of failure determined jointly by the likelihood and the consequences (Garvey, 2009) of a failure to manage cost, schedule and scope/quality. Thus, making probability theory work in concert with fuzzy set theory to deal with various types of uncertainties arising within the same problem is attractive.

2.9.2.1 Uncertainty Modeling Using Fuzzy Logic

The use of fuzzy set theory as a methodology for modeling and analyzing decision systems is of particular interest to researchers due to fuzzy set theory's ability to quantitatively and qualitatively model problem complexity (Grey & MacDonell, 1997), uncertainty (Gaonkar, et al., 2011; Guiffrida & Nagi, 1991), and imprecise data (Chai, et al., 2009).

Many problems associated with complex system development contain hidden attributes, therefore creating problems for the decision maker. These hidden attributes, therefore, cause problems to exhibit uncertainty and vagueness on some levels (See Figure 6). When dealing with decisions, many decision spaces lack sufficient depth to make an empirical valuation. Simple decision-making methodologies prove inadequate when complex system attributes are not substantiated with significant robust data.

Uncertainty associated with scarce data can come from numerous sources and can be difficult to reduce for various reasons. One such issue is the inability to collect data given the complexity and expense of modeling the system. Additionally, there are issues when addressing a problem at the boundary conditions. Complex boundary conditions of the problem space do not make simple compensatory evaluation techniques feasible nor will they produce significant results. Having said this, complexity and uncertainty, associated with decision-making evaluations do not lend themselves to simple system state condition methodologies such as crisp Markov system state analysis.

Complexity and uncertainty can be modeled in fuzzy membership functions (Zadeh, 1965, 1998); where uncertainty is addressed gradually on an interval evaluation. A fuzzy model can be developed which gathers information about uncertain events and situations and then provides information to make a decision.

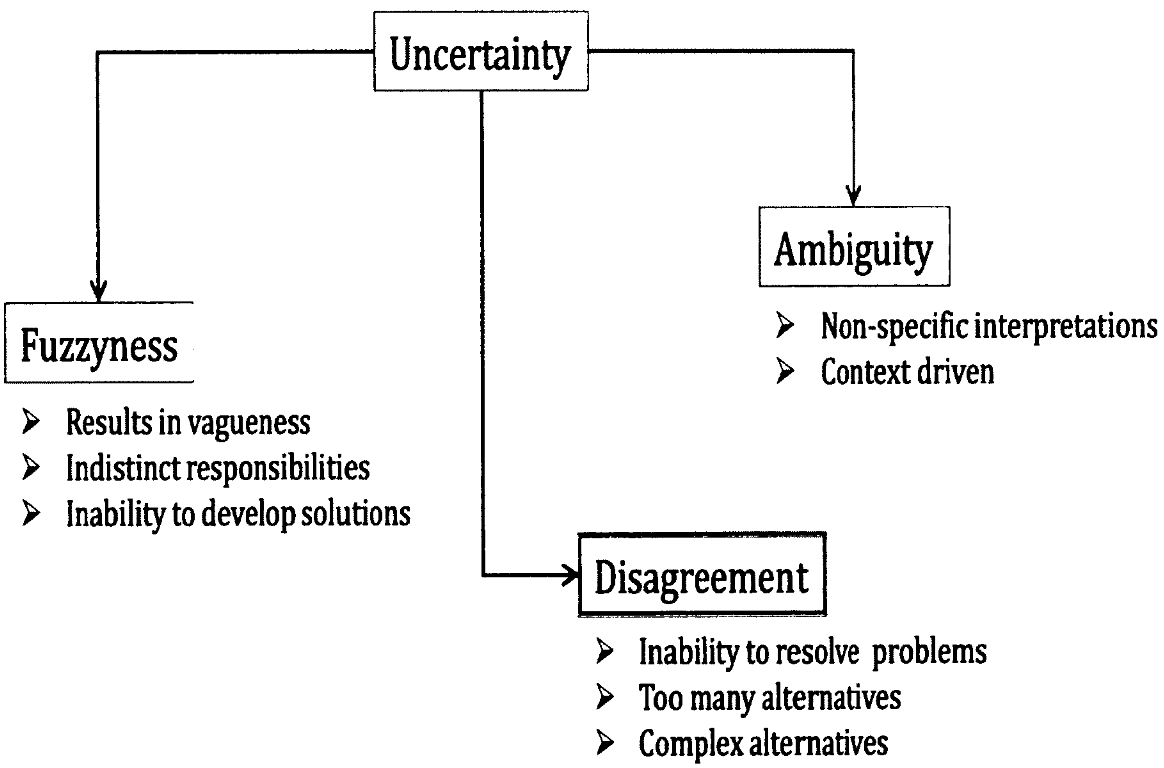

Figure 6. Uncertainty Adapted from (Klir & Yuan, 1995, p. 2).

A fuzzy model can be utilized in place of a deterministic model, which models the actual system with crisp inputs and outputs so fuzzy output can be used to facilitate the decision-making process (Lodwick, 2008). The fuzzy approach to modeling allows the decision maker to address areas where absolute knowledge is unattainable or too expensive to collect data to successfully model the system.

In addition to uncertainty, vagueness, according to Bezdek (1993, p. 1), is a lack of sharp distinction or boundaries, or lack of ability to discriminate between different states of an event. This condition is exacerbated by the gradual change in conditions which effect a state change in a system. So how does the decision maker address all these conditions? We must provide a systematic, mathematical framework to reflect vagueness, uncertainty and complexity with linguistic ambiguous criteria.

The fuzzy set analysis process provides a methodology to address these issues. A fuzzy set of relationships, models the knowledge about a system, not the system itself. The use of linguistic variables and the use of a fuzzy algorithm in decision analysis of long-range programs provide an approximation and effectiveness tool for analyzing the future state behavior of programs which are complex or ill defined (Dhar, 1979). Figure 6. Uncertainty Adapted from (Klir & Yuan, 1995, p. 2), graphically depicts the considerations that a decision maker should consider.

Since metric models are either difficult to quantify (for example, complexity), or are only known to a rough degree (such as system size), the use of fuzzy variables seems intuitively appealing. Grey and MacDonell (1997) hypothesize that project managers are able to model and provide reasonable estimates of programs and system development using fuzzy variables with reasonable levels of accuracy and consistency much better than output estimates from applications using crisp statistics.

2.9.2.2 Fuzzy Analysis of Uncertainty and Management

Fuzzy set models can be adapted as estimation and planning aids and provide complementary aspects to metrics which already exist. Fuzzy set models as described by Yahaya and Mohamad (2011) as well as others (C. Ding & Zhang, 2010; Grey & MacDonell, 1997; Kelemen, Kozma, & Liang 2002; Singpurwalla & Booker, 2004; Zadeh, 2002) may also provide avenues to evaluate planning and estimation efforts by using natural language, which is full of vague and subjective expressions. Fuzzy sets theory provides a mathematical modeling approach where vague and subjective expressions can be quantified and utilized in program planning and estimation efforts.

When making important decisions, a decision maker faces a daunting effort. Tools to help reduce the decision-making load are used today to help decision makers identify potential responses to hard decision issues. In their articles on application of fuzzy logic in software development, Molokken and Jorgensen (2003), Gray and MacDonell (1997), Yahaya and Mohamad (2011)and Krusko (2004) believe that fuzzy modeling processes can provide benefits in the evaluation of software tasks.

2.9.2.3 Fuzzy Modeling and Evaluation

Many researchers (Chai, et al., 2009; C. Ding & Zhang, 2010; Grey & MacDonell, 1997; Kelemen, et al., 2002; Lodwick, 2008; Lu, et al., 2006; Mamdani, 1977; Senglaub & Bahill, 1995; Signal Processing Magazine, 2007; Takagi & Sugeno, 1985; Yahaya & Mohamad, 2011; Zadeh, 2002) have developed algorithms for fuzzy inference models and fuzzy clustering, although few describe how or why it is important to set up possibilities and membership functions for fuzzy inference systems.

The membership function according to (Singpurwalla & Booker, 2004) provides a vehicle for developing operations with fuzzy sets, such as unions, and intersections. Membership functions were introduced as a way of dealing with the form of uncertainty of classification in fuzzy mathematics. Clearly, in fuzzy mathematics, the membership function is a subjective measure because it is specific to an individual or a group developing input for a fuzzy process to aid in decision-making.

Dhar (1979) developed an algorithm to provide decision-making assistance for long term planning for capital investments (i.e., New Power Plants) in the power industry. The process contains a straightforward algorithm that can be modified for other decision-making problems.

Along with Dhar's (1979) process for determination of suitability of the selection of alternatives, the author identified several software packages which may provide accurate and consistent estimates in the planning and estimating of technically complex programs.

The fuzzy analysis process allows decision-makers to include ambiguous information that can be identified while using preprocessing tools such as Logical Decision and Expert Choice software. Even though the data sets which act as input for fuzzy analysis algorithms are mostly crisp, they may also include ambiguity and linguistically ambiguous terminology for conditions that program planners feel contain inexpressible complexity, indistinct uncertainty and measureless vagueness.

Definitions must be developed for these inputs to reduce the combinatorial aspects associated with modeling complexity. Developing consistent definitions allow decision-makers to first focus on developing a solution for a wicked problem. Additionally, these definitions help reduce the input data set where not all of the measures of merit need to be included in fuzzy analysis if the criteria does not provide significant input to the model. Additional effort should be made to identify criteria which should be used to help the decision-maker derive a potential ranking of the alternatives should more than one alternative be required.

Fuzzy process algorithms and applications developed by various authors (C. Ding & Zhang, 2010; Grey & MacDonell, 1997; Guiffrida & Nagi, 1991; Jantzen, 1998; Jorgenson & Grimstad, 2011; Kaci & van der Torre, 2008; Kelemen, et al., 2002; Klingenberg & Ribeiro, 2011; Klir & Yuan, 1995; A. Kumar & Kaur, 2010; S. Kumar, et al., 2010; Paolucci, 2006; Senglaub & Bahill, 1995; Singpurwalla & Booker, 2004; Takagi & Sugeno, 1985; Yahaya & Mohamad, 2011; Zadeh, 2002) are able to address multiple stakeholders and worldviews. Many of the applications can vary input to analyze specific conditions associated with the decision being made. Most applications provide fundamental analysis calculations, where the author was able to process basic alternative sets very quickly utilizing software applications, such as the work of Lu, Zhang, Ruan and Wu (Lu, et al., 2006). Applications such as these should help reduce the effort required to process multiple data sets where the decision-maker can evaluate multiple conditions in near real time.

2.9.3 Failure Mode and Effect Analysis

Identification of potential failures in complex environments is critical for making failure-averse decisions. Currently, procedures such as Failure Modes and Effects Analysis (FMEA), Fault Tree analysis, or Failure Modes, Effects and Criticality analysis, as well as prior knowledge and experience, are used to enhance knowledge gathering to plan for potential crises. These procedures require decision-makers to have a broad knowledge of issues that could lead to a program crisis or failure and to understand causality in complex uncertain situations. If there is a lack of sufficient knowledge to predict all of the realistically possible outcomes, then the decision-making activities may fail.

As addressed by many authors (Batson, 1987; Carbone & Tippett, 2004; Chang, et al., 1999; Defense Systems Management College, 1989; Galway, 2004; Garvey, 2009; Goff, 2011; Hulett, 2005; Keskin & Ozkan, 2009; Long, 1985; Norris, et al., 2000; PMBOK; Stoneburner, et al., 2002; University of London, 2011), the failure to perform effective program management can cause projects to exceed budget, fall behind schedule, miss critical performance targets, or exhibit combinations of these issues. Having an effective method to identify, plan for and manage program risk is critical to successful program management. As projects increase in complexity and size, taking a multidisciplinary approach to project management requires tools and methods that are easy to use and apply when addressing risk, complexity and uncertainty.

Failure Mode Effect Analysis (FMEA) first emerged from studies performed by NASA in 1963 (Keskin & Ozkan, 2009) and then applied to the car manufacturing industry. The FMEA method is based on systematic brainstorming for uncovering failures that might occur in a system, a process or program. Traditionally, when performing a FMEA, three indices have been used: occurrence (*O*), severity of the associated effects (*S*) and detection (*D*) (Rhee & Ishii, 2002). The product of the three indices provides risk measurements, known as risk priority number (RPN) or Risk Priority Category (RPC) (Keskin & Ozkan, 2009). In deterministic models of FMEA, RPN and Pareto Charts have been used as the principal knowledge acquisition tools to represent and score failure modes.

In standard FMEA, either RPN or RPC, which may utilize subjective interpretations in measures of O, S and D, are used not only to construct the system failure effects model, but also to develop risk analysis processes and interpretations (Keskin & Ozkan, 2009) . Examples of input factors include failure probability, non-detection of faults probability, severity of failure effects, and expected cost to assess either RPN or RPC of the potential failure. The RPN and RPC based analysis suffer from shortcomings as outlined by Chang, et al. (1999) and Puente, et al.(2002).

2.9.3.1 Fuzzy Failure Mode Effects Analysis

To offset the effects of ambiguity and vagueness inherent in the crisp estimation and evaluation of failures, Kmenta and Ishii (2000) recommend that a scenario based FMEA method be used to identify failure chains (i.e. absorbing Markov chains). Carbone and Tippett (2004) address management risk as an essential element of successful project management where proper risk management can assist the project manager to mitigate risks on programs of all kinds.

To alleviate additional shortcomings of a standard FMEA, Jenab and Dhillon (2004), and Keskin and Ozkan (2009) present FMEA methodologies based on a fuzzy approach which takes into account that failures should be associated with ordered element sets such as risk priority categories corresponding to individual evaluations developed in a group setting where the comprehensive RPC for each failure is the aggregation of the RPC's of a specific failure. This aggregation of risk includes various uncertainties that are included in estimates made by members of the failure effect analysis team.

Outputs adapted from Tsoukiàs (2007), can be used as input for a fuzzy inference system when developing risk attributes to evaluate. However, each of these methods must also take into account additional limitations to failure effects analysis in a program planning setting. In this project, it is important to understand that there are several issues which complicate the analysis of the existing data.

These include issues such as lack of explicit links between program tasks and the risk calculations may not identify complexity between linked tasks.

Risk Scores such as RPN and RPC, normally used independently, can provide added dimensionality when used together and then can be mapped via a radar graph to identify potential disconnects in the risk evaluations. Addressing risks simply based on individual risk scores alone might be addressing risks that could be easily detected and dealt with much later or in a different manner.

However, lack of identification of these inconsistencies may be catastrophic for the program, given that lower risk scores based simply on risk score RPC or RPN alone do not provide a complete picture of risk. One problem with the standard FMEA RPN and RPC is that the value may not be sensitive to other components of a program that require consideration. As seen in Figure 7, the comparison of data indicates that the project phases have differing RPN and risk score RPC evaluations. This is very obvious in the radar plot.

Care should be taken when evaluating the RPN or RPC as a standalone evaluation metric. Again, the main insight is the distribution of the values and that the risks that have high risk RPC scores do not necessarily have high RPN scores.

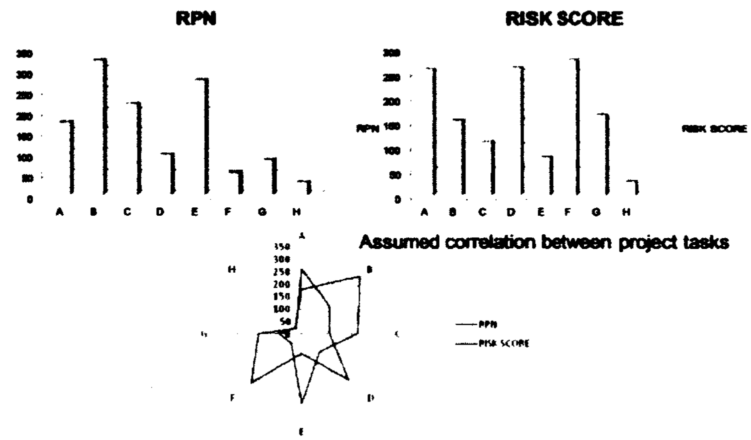

Figure 7. Risk Score RPC Versus RPN.

To reduce the overhead burden associated with risk analysis, it is intended that a FMEA process be performed by computer, which can be very efficient and prevent possible errors in the analysis.

2.9.4 Markov Systems

A Markov system (Waner, 2004) or Markov chain is a system that can be in one of several states and can pass from one state to another for each state transition according to fixed probabilities.

A Markov chain can be illustrated by means of a state transition diagram, which is a diagram showing all the states and transition probabilities (Attal-Sakhadev, n.d.). If a Markov chain is in state i, there is a fixed probability, p_{ij}, of it going from state i into state j during the next transition step. This probability p_{ij} is called a transition probability. Markov chains, according to Mentch (2011) and Revere and Large (2006), are useful in constructing a mathematical model of a situation involving experiments with multiple outcomes where the outcome of a given trial depends only on the outcome of the previous trial. Often, mathematical models such as Markov chains can be used as tools for making informed decisions. Thus, for the general Markov process, we have an efficient way to calculate the probability of moving from one state to another state. This is very important when performing analysis to determine if a given system states entry is highly probable. The interest associated with the Markov process is when the next state of a system cannot be exited. This state is called a Markov absorbing state. Buckley and Eslami (2002) provide a very detailed discussion on the crisp and absorbing Markov process.

2.9.4.1 Absorbing Markov Systems

An absorbing state (Revere & Large, 2006; Waner, 2004) is a condition in a Markov chain from which there is a zero probability of exiting. An absorbing Markov chain is a system which contains at least one absorbing state, where it is possible to get from each non-absorbing state to an absorbing state in one or more state transitions. The question asked by Mentch (2011, p. 5) is "How many states will we be able to reach before reaching an absorbing state?" This question is of interest to this investigation since that the hypothesis is that a program will reach an absorbing state where the three program constraints are strictly defined and invariant. On average, how long will it take for the system state to fail to keep within the schedule, cost or scope/quality constraints?

In an interview with the Innovative Leader, Mitroff (1998) indicates that questions with these characteristics generally lead to a type III error condition, where a solution is not identifiable. How is an absorbing state evaluation to be undertaken? Zadeh (1998) describes processes and methods that allow for uncertainty and ambiguity to be included into a Markov chain process. Gaonkar, Amonkar, Sakhardande and Kamat (2011) provide a very good discussion on the employment of a method that can be used for this project, the Fuzzy Absorbing Markov process.

2.9.4.2 Fuzzy Absorbing Markov Systems

The utilization of fuzzy absorbing Markov systems has been suggested by many researchers (Kleiner, Rajani, & Sadiq, 2005; Leuschen, 1997; Mentch, 2011) as a method to exploit the robustness of the Markov process and the flexibility of the rule-based fuzzy techniques and their ability to handle imprecision (Zadeh, 1998) and transitional probabilities. The approximation of the distributions of the Markov transition matrix which captures the probability of transitioning from one state to another is possible through discretization. Fuzzification should be considered a generalization of discretization, where continuous variable distributions can be approximated by fuzzification.

The major benefit, according to Leuschen (1997), of using fuzzy models is that they preserve uncertainty and possibility accurately throughout the state transition calculations, so that uncertainty in the input propagates through the model and output uncertainty is correctly determined. The system state diagram example for this project is captured in Figure 8. This diagram provides a depiction of the system states and interactions which can lead to a program crisis, like an absorbing Markov state. This Markov state diagram is laid out so that interactions can create a four level crisis in project management. The absorbing Markov state, a defect, cannot be transitioned from unless explicit program management interaction is provided.

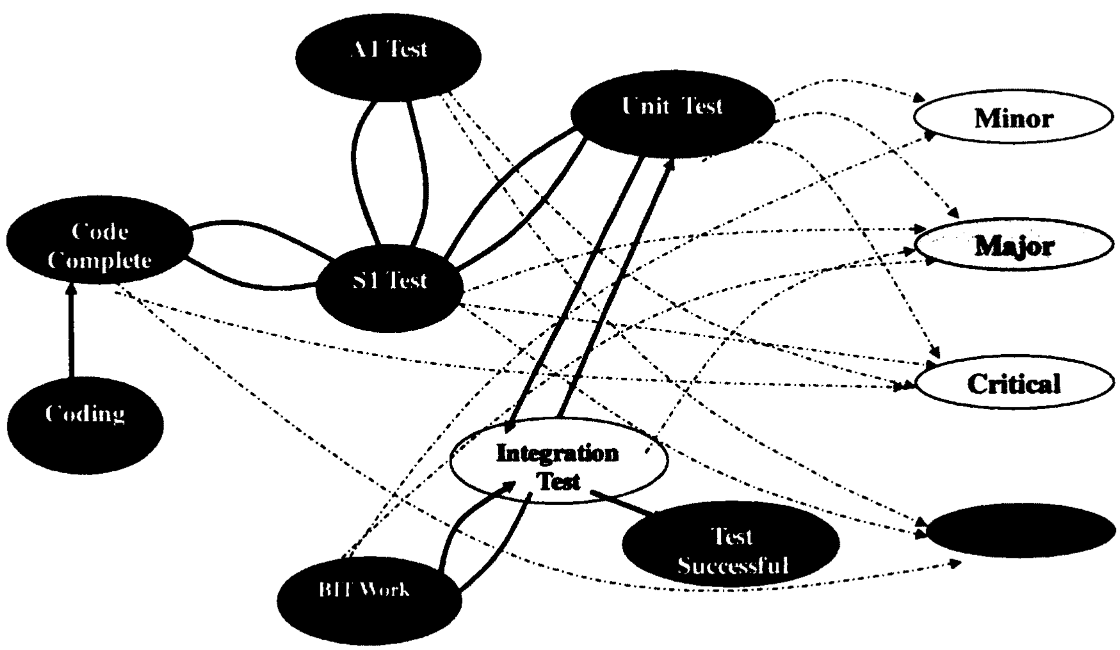

Figure 8. Markov System State Diagram.

Leuschen (1997) analyzes several specific fuzzy Markov functions. Given that a program follows the characteristics of a machine (working, damaged, failed), the results identified by Leuschen are applicable to this research. Implementing a Fuzzy Markov Model (FMM) approach through closed sampling appears to be a viable model which meets all the requirements as defined by (Leuschen, 1997) for FMM to be utilized in this project.

A FMM can best be understood if a process which outlines the steps is presented. For this research's purpose, the utilization of this method provides a technique for addressing the failure modes of a program, where schedule, cost and scope are compared to motors, sensors and power. Schedule can be subdivided / layered into tasks, complexity, duration and critical path potential.

This layering allows details of complex programs to be addressed. The identification of fault tolerances for defects, schedule delays, and cost overruns can be applied where critical path analysis can be augmented to transform certain failure modes into transient effects that do not cause the program to fail. This augmentation can be approached through three steps: (a) modeling the risk and crisis as a fuzzy Markov process to obtain possibilities and a transition matrix, (b) combining the possibility of failure with detection possibilities and fuzzy consequences to obtain the fuzzy risk of failure throughout the program, and (c) using a fuzzy risk model to anticipate and evaluate elevated risk indicators and crisis levels to make effective informed decisions (Kleiner, et al., 2005).

This approach to crisis management must be planned and implemented early enough that the potential crisis risk is reduced. A potential complication of this approach is that details of the crisis may have become aggregated so they are not obvious and may require further investigation at the task level to determine root causes.

2.9.5 Data Clustering

Certain attributes of the data to be collected for this project indicate that investigating clustering of information could provide additional program management insights when performing crisp and fuzzy analysis of the schedule. Through the investigation of the differences between crisp and fuzzy clusters, it is proposed that unqualified program task estimates can be identified. Thus, through the use of data clustering, the source of questionable estimates of task duration, task effort and other planning attributes may be determined and linked to the estimator.

Cluster analysis is a multivariate statistical procedure (Arunajadai, Stone, & Tumer, n.d.) that starts with a data set and attempts to organize samples into relatively homogeneous groups. The purpose of clustering relational data is to identify natural groupings of data from a large data set to produce a concise representation of a system's behavior. Hathaway, Bezdek, and Davenport (1995) describe relational data as objects specifying pair-wise similarities. Karaboga and Qzturk (2010) indicate that the goal of clustering is to group data into clusters so the similarities within the same cluster's data members are maximized while similarities from different clusters are minimized.

Clustering, according to Velmurugan and Santhanam (2010), is utilized in many different applications, such as data mining, knowledge discovery, pattern recognition and pattern classification. New approaches have to be developed to deal with large amounts of data, that are heterogeneous in nature (numerical, symbolic, spatial, etc.). Many methodologies have been proposed in order to organize, to summarize or to simplify a dataset into a set of clusters so the data belonging to a cluster are similar and data from different clusters are dissimilar. The clustering process is usually based on a proximity measure or, in a more general way, on the properties that data share.

Clustering of numerical data forms the basis of many classification and system modeling algorithms. Clustering procedures generally take on two forms. The first approach is statistically based, and uses algorithms such as the K-means (S. Ding, Xu, Zhu, & Jin, 2011), which is a crisp clustering approach. The second procedure, fuzzification, uses an approach as implemented in the fuzzy C-means clustering algorithm(Izakian, et al., 2009). These two approaches will be discussed in the next sections.

2.9.5.1 Crisp Clustering

Cominetti, Matzavinos, Samarasinghe, Kulasiri, Liu, Maini, and Erban (2010) address the need to interpret and extract possible inferences from high-dimensional data which has led to the development of dimensionality reduction and data clustering techniques. One of the data clustering methodologies is the K-means algorithm (Izakian, et al., 2009; Karaboga & Ozturk, 2010), which is an example of a crisp clustering approach.

These algorithms are generally traditional clustering methods which do not allow data points to belong to more than one cluster at the same time. The performance of crisp clustering algorithms has been addressed by many authors. Many researchers (Chai, et al., 2009; C. Ding & Zhang, 2010; Grey & MacDonell, 1997; Kelemen, et al., 2002; Lodwick, 2008; Lu, et al., 2006; Senglaub & Bahill, 1995; Signal Processing Magazine, 2007; Zadeh, 2002) believe that, despite the benefits from developing crisp models, there are a number of problems that have not been overcome using the traditional techniques of standard linear regression models.

These problems include nonlinearities and interactions inherent in complex real world processes. Over-commitment and task duration underestimation are examples of explicitly specified values where the inability to use whatever knowledge is available or where exact numerical values are unknown manifest themselves in program planning and estimation. The use of an alternative technique for clustering, especially fuzzy logic clustering, is investigated further in the next section.

2.9.5.2 Fuzzy Clustering

Fuzzy clustering is an important approach to clustering data and is the subject of active research (Izakian, et al., 2009). The most frequently used algorithm is the fuzzy c-means (FCM) algorithm because it is efficient and easy to implement. FCM is an iterative algorithm, according to Pelekis, Iakovidis, Kotsifakos, and

Kopanakis (2007), in which the intent is to find cluster centroids that minimize functional criteria, thereby measuring the quality of a fuzzy cluster.

FCM is a soft clustering approach that generates fuzzy partitions for a given data set. In the case of FCM, the clusters to be identified do not have to be well-separated as is the data for this project. The FCM method assigns cluster membership probabilities to loosely-coupled elements of the data set that cannot be readily assigned to a specific cluster. Each data point belongs to a cluster to some degree that is specified by a membership grade. This technique was originally introduced by Jim Bezdek in 1981 (Bezdek, 1993; Karaboga & Ozturk, 2010).

Challenged by real-world clustering problems, the FCM clustering algorithm copes with uncertainty and uses a similarity measure between fuzzy sets. A major challenge posed by real-world clustering applications is dealing with uncertainty in the sample sets. Considering that feature values may be subject to uncertainty due to imprecise measurements and noise, the distances that determine the membership of a feature vector to a cluster will also be subject to uncertainty. Therefore, the possibility of erroneous membership assignments in the clustering process is evident. Current fuzzy clustering approaches do not utilize any information about uncertainty at the constitutional feature level (Pelekis, et al., 2007).

As used in this project, data clustering (Eschrich, Ke, Hall, & Goldgof, 2003) algorithms, can be used to partition unlabeled data. Clustering or partitioning of data sets can be described by real valued feature vectors and may be better understood if they are partitioned by a fuzzy clustering program. Such data sets have been created in the process of evaluating this project's program task durations, work completed, and task start dates, in addition to other data set features.

2.10 SUMMARY

Options for addressing decision processes need to be documented such that strategies may be successfully integrated into the decision making process and model development to provide rigor in uncertain, subjective situations. Coupling this with understanding of the requisite variety of the situation and other systems analysis paradigms and knowledge gathering activities, it is conceivable that we can propose a richer form of analysis and evaluation than an unsophisticated approach to understanding complexity and the decisions that are made under uncertainty.

Complexity and uncertainty do not allow for a ready-made set of solution alternatives that the stakeholder or knowledge gatherer can pull from the shelf. Acceptance of new methodologies to analyze complexity will continue to be difficult, simply because analyzing complex problems is time variant and perspective dependent.

The more knowledge that is gathered about a system does not necessarily mean that the knowledge will benefit the analysis and provide insights to reduce the uncertainty of the situation or improve the understanding of the system. However, through the utilization of the preceding topics and techniques, the author will analyze data and provide recommendations so the reader may verify that there are methods that can be utilized to improve the accuracy of input data, thereby enhancing decision-making associated with the program management of complex technical programs. While the methods chosen will be specifically applicable to DoD system development programs, it is the hope of the author that this approach will be capable of being utilized in a more generalized program management effort.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The program under study is a complex system. A complex system as defined by Fowlkes, Neville, Hoffman and Zachary (2007) contains multiple relations between stakeholders and often incompatible objectives which make program management difficult. These conditions are incompatible with standard program management approaches and methods that attempt to decompose complex environments into distinct elements for further analysis. This chapter documents the methodology and evaluation process for selecting data elements for analysis, analysis techniques and output descriptions for project evaluations. In order to effectively develop a set of heuristics for decisions associated with the research project, many questions need to be answered. Several key decisions points for the research project are discussed below.

3.2 RESEARCH STRATEGY

To identify a research strategy, the author evaluated Creswell's (2003) research paradigm definitions, which are Quantitative, Qualitative and Mixed. Additionally, a method described as hybrid[1] was considered. After evaluating the

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[1] "In order to describe the structure and dynamics of complex social systems new approaches and research methods are required. In this sense, a wider and more appropriate set of methods must include quantitative as well as qualitative approaches. Also, a hybrid method mixing inductive and deductive approaches may result in a more effective way for understanding, modeling, and intervening in complex social systems, as the ones commonly found in Engineering Management." (Sousa-Poza, Landaeta, Bedoya, Bozkurt, & Correa, 2004, p5)

methodologies, a quantitative method appears to be the preferred approach to use in this study, along with the inclusion of contextual information to provide for a better understanding of the constraints which bound the decisions of program management on this program. Additionally, context will be added through background information and interpretation of data via Schedule and EVM analysis.

This research and the associated nature of the project lend themselves to the applied research field. The approaches and elucidations identified will correspond to a practical situation encountered on the RFEBC program. The applied research approach involved developing an understanding of the circumstances under investigation by using existing theories and methods to gain insights as to how the RFEBC program vendor managed the cost, schedule, and scope constraints.

In applied research, hypotheses can be refined depending on newly collected insights or facts. Sousa-Poza, Landaeta, Bedoya, Bozkurt, & Correa (2004) explain that this can occur when changes in program management efforts require an understanding of the organization and phenomena before a new process strategy can be developed. This project falls into the above category and has required that the author develop a deeper understanding of the organization and processes used in communication and evaluation of the program status data.

3.2.1 Quantitative Evaluation

To identify potential products for inclusion as decision-making aids, this project has investigated the interactions between the two primary information sources available for engineering management professionals to make decisions. The first source of information is financial data and reporting of projects. The second source is technical data and progress indicators such as the metrics produced through schedule analysis (i.e., task durations, associated levels of work) and product defect analysis (i.e., trouble reports and proposed solutions).

During the research, schedule, cost and technological impact were selected based on their level of commonality with program management literature of Taylor (2007), and Kerzner (2006), as well as the systems engineering literature of Blanchard and Fabrycky (2011). Program management schedule assessments were used to ascertain value associated with the research and data analysis. Since the EVM literature research indicated that few automated tools exist which would allow for sophistication, comprehensiveness, and applicability to the level desired for this effort, the author decided to begin investigation and development of a process which could be utilized in conjunction with existing EVM program and schedule assessment tools, and also provided added value to existing tools used by the sponsor of this effort.

Specifically, Matlab/Simulink applications and toolkits were assessed in conjunction with the literature reviewed for development of the data analysis methods and potential inclusion in this document. Additionally, heuristics have been developed from the data analysis to help determine the magnitude of the anomalies found during data analysis.

To support the above representations, data have been collected over the course of the two year program. Summarized data and specific program data products have been collected and processed. Data from the vendor has been reviewed and used by U.S. Navy schedule analysts and cost accountants to project the progress of the program. This data consists of monthly schedules, EVM assessments, variances and progress indicators, milestone achievement and delinquency data, resource staffing and program execution against the baseline schedule. These data provide a very good representation to assess the apparent health of the program. However, there were several instances during the program where the data provided indications that the program may not be as healthy as portrayed. These issues prompted this research. Program schedules, delivered each month, were processed to sanitize the attribution information in the deliverables. These schedules were then reviewed for anomalies. This information is provided in the results section of this document.

3.2.2 Qualitative Evaluation

Contextual data is generally addressed through qualitative data analysis. It is not the intent of this project to undertake a full qualitative analysis of the program environment. The intent is to provide a means from which qualitative data can be included and analyzed to augment the overall decision making process for program management in this project.

3.3 RESEARCH DESIGN

In order to make a decision and determine the main focus for this effort, a problem needed to be selected. Since a large data set existed very early in the research, a grounded theory research approach was utilized to develop a theory about the program environment, program characteristics and context from which data could be drawn and analyzed. Given the volume and nature of the program data, a quantitative approach was selected to analyze the data and develop heuristics for consideration.

An initial investigation of potential data products was conducted through the review of program management literature, independent research reports, and review of program management technical publications. The result of this investigation was a reduced list of potential project data element products such as those used in software schedule metric evaluations. Software schedule metrics, according to Smith (2003), track the contractor's performance towards meeting commitments, dates, and milestones. While milestone performance metrics provide a representation (data plots and graphs) of program activities and planned delivery dates, this information is not adequate when programs reach crisis conditions such as those encountered during the execution of the program under study.

Fowlkes, Neville, Hoffman and Zachary (2007) believe that it is appropriate to adapt current methods and develop additional constructs to better cope with the highly interrelated and continually changing characteristics and elements of the complex programs that are common today. To accomplish this goal, the problem needed to be clearly and concisely stated and the issues adequately narrowed to a problem with an appropriate scope.

While additional topics have been covered in the literature review, including Markov absorbing state analysis and fuzzy logic analysis, the development of enhanced EVM progress indicators was deemed the most productive to provide an immediately useful product to the sponsor of this research effort. The main decision was to focus the research and eliminate non-essential issues to answer the research question. Can the data from standard EVM reports and Integrated Management Systems (IMS) data elements provide adequate insight to develop progress indicators for the research project? The Milestone Progress Indicator (MPI) and the Resource Allocation Indicator (RAI) were developed to perform analysis of data from the program evaluated during this research project.

3.4 RESEARCH AND ANALYSIS VALIDITY

Validity refers to the approximate truth of propositions, inferences or conclusions. Trochim and Donnelly (2007), Creswell (2003), and Leedy and Ormrod (2005) believe that the researcher should consider both internal validity and external validity when designing a research project since conclusions are valid and meaningful only when based on the data collected and are applicable beyond the specific research environment being studied. The next sections will discuss these issues.

3.4.1 External Validity

External validity refers to approximate truth about the conclusions that involve generalizations or more broadly, the generalization of conclusions. External validity is the degree to which the conclusions from this program hold for other programs which may have similar circumstances (Trochim & Donnelly, 2007).

Leedy and Ormrod (2005) recommend using basic research designs, real life settings and stringent data constructs to improve generalizability and, therefore, external validity. Since this project utilizes a real-life setting with a practical research construct and has a potential to yield results with broader applicability to other technically complex programs, it is important to develop an approach and model program characteristics which can be utilized on similar technically complex programs.

Leedy and Ormrod (2005) introduce issues where the lack of representative sampling is a threat to validity and generalization. Representative sampling is addressed since the programs that will be compared to the baseline program will be measured through the gradient of similarity. This is required since we want the data in the research study to be generalizable to other programs. This is being accomplished through the collection of data from accepted program management tools.

Leedy and Ormrod (2005) believe that validity can be strengthened through replication of results in differing contexts when additional research is conducted on similar programs with different characteristics which reach the same conclusion. Under such circumstances, these results, when taken together, provide evidence that the baseline program conclusions have validity and applicability across diverse program characteristic context and environments.

Trochim and Donnelly (2007) believe that the researcher can do a better job of describing the ways environmental context is similar to and different from others by providing a measure of the degree of similarity between various characteristics which define the environment of the complex program.

An approach developed by Campbell and Stanley to ensure validity, especially external validity, is called proximal similarity modeling (Trochim & Donnelly, 2007). With proximal similarity, generalizability contexts are used to develop a theory with respect to program characteristics that are similar to the program that is used as the baseline. When programs have been categorized with respect to specific characteristics and environmental context in terms of their relative similarities, the researcher can be reasonably sure that the findings from the baseline program can be applied to the program that is to be studied.

Trochim and Donnelly (2007) call this implicit theoretical dimension a gradient of similarity and use this concept to identify conditions and characteristics which allow for findings to be applied to studies that lie within the boundaries of the gradient. This allows the researcher to develop a framework and decide if additional programs can be used with the same approach and methods. Thus, the researcher can generalize the results of the baseline study to other environments and programs that are similar to the current program under study.

It is believed that the following characteristics should be applied to determine if a target program lies within the similarity gradient boundaries. The similarity gradient evaluation includes characteristics such as:

- Contract Type
- Schedule Length
- Resourcing and Staffing
- Program Complexity
- EVMS Tailoring
- And IMS Reporting.

The characteristics listed above should be used as a minimum to develop a gradient of similarity to help determine the applicability and generalizability to other technically complex software intensive programs. Given the framework above, the similarity of the characteristics can be calculated and the similarity between the baseline program and the target program can be measured.

However, Trochim and Donnelly (2007) indicate that these generalizations are always a question of more or less similar conditions. Programs with characteristics and context that rank high along the gradient of similarity can be generalized with more confidence.

In the case of this project, the ability to characterize each individual characteristic's axis of similarity is important. The axis of schedule length, program complexity and resourcing and staffing are the most problematic and subjective of the measures to develop a similarity profile for generalizability. These measurements for the schedule axis may be calculated through the use of a simple one through ten (1-10) scaling mechanism, where five is considered average schedule length, average complexity and where resourcing and staffing availability is adequate. This baseline project is considered average with a measure of five (5) for the twenty-four month duration of the program, and with average EVMS Tailoring and IMS Reporting. Complexity is considered an eight (8) since the program experienced multiple technological delays where subsystem development delays and defects were the reason for schedule delays. Staffing and resource availability was considered average and is measured at five (5), since personnel were available at critical events.

The axis of contract type, EVMS tailoring and IMS reporting can be evaluated to determine the reporting period, the reported data, and the type of contract. The characteristic axis of type of contract is the least problematic where a simple scaling function may be used to measure the similarity gradient. The Firm Fixed Price contract is considered the most difficult to execute. This contract is measured at ten (10), the most restrictive and inflexible. Other, less restrictive contracts should be measured between one and ten (1-10), with less restrictive contracts having a lower value. EVMS tailoring and IMS reporting axis measures must contain data that can be used to calculate the MPI and RAI. This data should include task identification, task start date, task finish date, task duration, percent work complete, type of staff, and quantity of staff, at the task level which can be aggregated to higher levels such as the milestone level of reporting. Additionally, task owner information should be included so that deviations and variances can be traced back to the responsible capability manager. An example for this construct can be seen in Figure 9.

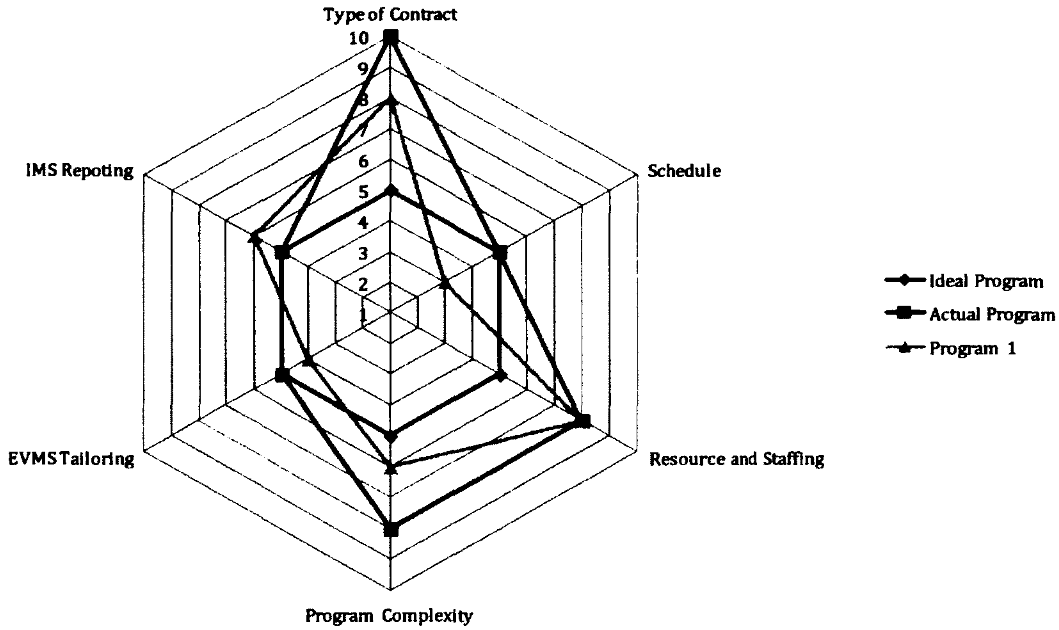

Figure 9. Gradient of Similarity.

Variations in schedule length and issues with EVMS tailoring may limit the generalizability for the example Program 1, in Figure 9 depicted above. Before applying the enhanced progress indicators to Program 1, specific elements of EVMS, tailoring and schedule length should be addressed to ensure that the appropriate levels of data are supplied to calculate MPI and RAI.

3.4.2 Internal Validity

Internal validity, as described by Leedy and Ormrod (2005), can be affected by several conditions. These include reactivity and experimenter expectancy. These conditions have been accounted for and conditions to counter them are addressed below.

3.4.3 Threats to Validity

In defining threats to validity, Trochim and Donnelly (2007) and Creswell (2003) provide an explanation of how a researcher may be wrong when making generalizations. External validity threats arise when experimenters draw incorrect inferences from the sample data to other programs with differing environments and characteristics. These threats arise because of the characteristics selected for the sample, the uniqueness of the setting, and potentially, the timing of the experiment.

Given the explicitness of the similarity gradient framework, the threat of program uniqueness is reduced, or at least, relegated to specific vectors of the gradient. The strict data evaluation processes, used to develop the heuristics, do not rely on timing of reporting or the time of the execution of the program. It is not expected that the research will suffer from a temporal effect, given that many programs are executed over extended lengths of time.

The most common loss of external validity comes from the fact that experiments often employ small samples obtained from a program with specific characteristics which do not exist in other programs. This issue does not affect this research since a large data set exists to support the evaluation of the MPI. The data set includes twenty six months of program schedules with thousands of tasks and hundreds of milestones each. Data supporting the analysis of the RAI also consist of twenty-six months of data. In this case, the specific features of the firm fixed price environment potentially extrapolate very well to much less restrictive program environments which allow one or more of the program constraints to vary.

Reactivity is not expected to affect the collection of data, since all capability managers must provide regular progress reports to the program manager. Capability managers will not change their behaviors because they do not know they are providing insight into progress for areas of the program for which they are responsible.

Experimenter expectancy will not affect the collection of data given that people providing data on program progress are not aware that the data is being utilized to further evaluate heuristics to improve decision-making associated with the program.

Creswell (2003) focuses extensively on processes that utilize data gathered directly from surveys which require extensive care in the gathering of the data. This will not be an issue for this research project given that surveys and interviews will not be used. This project focuses on the analysis of hard quantitative program data.

Deliberate care was taken to ensure that researcher bias and researcher as a participant interactions do not taint the data collection process or the data itself. The data collected in this research effort have avoided these conditions since the data and the data collection process was developed as part of the standard reporting process in earned value management. The specific data elements to be analyzed during data analysis were included as contract deliverables in the contract. The author was not required to be involved in the data collection process directly, thus avoiding the above threats to validity.

3.5 DATA COLLECTION AND EVALUATION

Experienced program managers are generally provided with tools to manage projects of substantial size through the utilization of program management software packages. Almost all of the data provided for monthly analysis is automated to provide an upper management dashboard for the program.

3.5.1 Data Review

While program management support tools provided program health indicators and trend analysis of the current state of the program, it was not until the vendor products were reviewed that program anomalies were linked to specific issues presented during the weekly, monthly and quarterly reviews of the vendor provided data.

The data provided insight into the day-to-day operations of the program. However, the EVM metrics (BCWS and ACWS) and status indicators (SPI and CPI) did not provide insights as to the direction that this project research should have taken to understand the long term trends that the program was exhibiting.

3.5.2 Data Selection

In general, project management software program scheduling capabilities are excellent. Project management software packages allow users to perform accurate calculations for many types of task relationships, and provide the capability to identify project critical paths. Schedule and resource data can be filtered and rolled-up for clear, effective management reporting. A variety of preset management reports and histograms are provided in most project management software packages. Project management software products also offer extensive project management capabilities such as earned value, resource management features, risk scenarios, and customized reporting. Program management emphasis is placed on the review of outputs of these packages, which include prioritization of risks, scheduling issues, and allocation of resources.

Many program managers utilize the basic output of these program management packages exclusively to manage programs. While these packages provide significant insight to the workings of complicated programs, it is believed that further analysis of this output is warranted. Therefore, the following analysis is proposed to glean additional findings from data such as those listed above.

3.5.3 Data Collection

Data was collected over the period July 2009 through September 2011 and contains the basic EVM metrics such as the budgeted cost of work scheduled, the budgeted cost of work performed, actual cost of work performed, cost performance index, and schedule performance index. The schedule (IMS) data products include schedule components such as start date of the task, duration of the task, work hours associated with the task and the amount of work completed against the task. It is the evaluation of this data from this type of product that forms the basis of this project.

The decisions made in selecting the data elements which included schedule details (start date, finish date, work hours, slack, work progress), cost details (BCWS, ACWS, EAC, contract cost information), and resource allocation (staffing levels) were derived after evaluating the program management tools used in the program under study. The decision was made to include specific investigations into monthly reports from the program vendor's EVMS, IMS and sponsor developed program management tools. The list of data elements required to substantiate the research of this project is included in Appendix A: Data Element List.

Berry (2000) believes that data can be made to produce program management results that satisfy our expectations. However, program management does a poor job of developing expectations. This statement highlights the importance of deciding what data should be collected for analysis early in the project. This is especially important in selecting the data elements and sampling methodologies for this project where the ability to request additional data was restricted. It was very important to recognize that the data selected for analysis should provide a productive output for the sponsor. Therefore, a cautious approach to select data for analysis was required. Since the program under study was contracted as a fixed price contract, any requested data, outputs or reports, unless specifically delimited in the contract, could be considered a government change in contract scope by the vendor, thus evoking a contract modification and cost growth.

One of the difficulties faced during data collection was trying to determine which components of the data sets were important. This was hindered by the fact that most data was associated with high priority risk areas previously identified to address existing schedule slips and cost variances, which were then used to explain the plan to recover or maintain EVM schedule and cost improvements. Minimal attention was applied to potential future high priority risks, thus the decisions made from the analysis by the vendor involved a reactive approach to program management instead of a proactive approach. This was evident in the EVM reports which indicated schedule slip and cost growth through reported schedule and cost variances each month. Therefore, the decision was made to develop a progress indicator which would help to introduce a proactive approach to identify high priority issues at the next lower reporting level.

3.5.4 Data Sampling

Data sets needed to be evaluated to clearly outline how the data was to be analyzed. Specific consideration was taken to utilize existing data elements and products that were available from the contract. In developing the selection criteria for sampling data, the data was coded (personally identifiable information was encoded) to ensure anonymity then sequenced (applicable data elements were linked to the encoded task owner information) and the data selection evaluations were accomplished through the following steps:

Step 1: Identify problem areas and identify select data sets- Do data elements exist that will support the analysis? Milestone completion and resource allocation data from IMS contract deliverables support this effort.

Step 2: Identify objectives and goals for the use of the data – Will the data support the research, and will the data provide significant insights through the analysis? Results were developed which support this step.

Step 3: Analyze EVMS outputs and associated data elements – Understand the basics of EVM and data used to calculate BCWS, ACWS, EAC, SPI and CPI. Results were developed from EVM outputs which support this step.

Step 4: Determine criteria for analyzing IMS data elements –Milestone, task completion, and resource allocation data must exist to calculate MPI and RAI. Results were developed which support this step.

Step 5: Validate program environmental constraints – Is the data valid? Results were developed which support this step.

3.6 SCHEDULE PERFORMANCE EVALUATION

Data element review and selection was required to define a representative set of data elements that constitute project data for analytic and synthesis considerations. This includes data required for the planning, estimation, execution, and control of a program.

The review process consisted of defining analysis requirements, defining project management data elements, producing a reduced data element list, then data selection and evaluation. The first step of the review process was the identification of project management data elements. These data elements were defined in such a way as to ensure consistency of project management information that could be used to form a basis of comparison for generalizability.

To support the steps above, schedules were loaded into a MS Access database. Queries were developed to segregate the data. It was this analysis which indicated that many tasks and milestones did not have work hours associated with them to measure the level of effort required to successfully complete the program. The detailed program schedule analysis included breaking the schedule up into milestones, non-milestones, tasks with hours of work associated with them and tasks with no work hours associated with them. This analysis also indicates that the program schedule and WBS were inaccurate at projecting the level of effort required to complete the program. Data sets which included information on complete and incomplete milestones were reviewed. Program status data sets exhibited anomalies where the completed and uncompleted milestone count changed from week to week. Analysis of these data anomalies helped to focus the research to develop enhanced progress indicators for the project. These issues are discussed further in Chapter 4.

In work similar to this research effort, Octeau (2010) describes several enhancements to evaluating schedule indices and variance calculations for schedule performance (Equations 3.1 – 3.3), where:

Schedule Performance = % Spent / % Scheduled (3.1)

and

% Spent = Cumulative ACWP / (Best : Most Likely : Worst) EAC (3.2)

% Scheduled = Cumulative BCWS / Original BAC (3.3)

While the work above is interesting, the approach does not add significant insight into the measure of quality of the program since it uses inputs which may be inaccurately reported. The schedule performance that was reported on the program under study contained inaccurate data, therefore such inputs as % Spent and % Scheduled may not be valid inputs to evaluate the program status.

The following section will focus on similar issues associated with program analysis as they relate to EVM and milestone completion. A quality value measure, which may be used as an objective indicator, is proposed. To accomplish this effort, the proposed quality measure must provide an adequate basis for responsible decision-making for both vendor program management and governmental program management. This can be accomplished by requiring that a vendor's internal management control system produce data that links technical accomplishment to work progress and schedule performance.

3.7 MILESTONE PROGRESS INDICATOR DEVELOPMENT

Program management utilizing EVM is hampered by the lack of consistent assessment of earning rules, where milestones may be defined and assessed differently by sponsors and vendors. These findings and the others detailed in this report suggest the need for research into a mechanism to provide unbiased analysis of a program's progress. Therefore a Milestone Progress Indicator (MPI) heuristic has been developed (Equations 3.4 - 3.11) which measures work not accomplished. The indicator is tempered with the work accomplished for current efforts and future efforts. The MPI can be calculated by using the following definitions and equations. Terms and definitions have been formalized to represent the concepts associated with each equation and development of the progress indicator. Data elements supporting the calculation of the MPI must be derived from analysis of monthly schedules from the vendor. Independent analysis ensures that vendor bias is not included when calculating the MPI. The researcher must ensure that the following set of elements is available in the schedule to successfully calculate the MPI.

One method, short of having someone else provide the data for calculating the MPI, is to first filter the schedule to obtain the required data for the reporting period. This is accomplished by importing the schedule into MS Access. Queries were developed to provide data subsets for analysis. Pseudo code is included below to explain the logic to accomplish this task.

The query was set to include only tasks that were to be executed during the reporting period. To calculate the planned milestones for completion, *Mp*, during the evaluation period, the finish date element for the milestones was used to determine if a milestone was applicable to the reporting period. The count of the milestones was calculated to determine the number of milestones that were planned for the reporting period. The pseudo-code for this calculation is:

If milestone finish date is in reporting period then count this milestone.

To calculate actual milestones completed during the evaluation period, *Ma*, the percent complete element was used to determine if the milestone had been completed, thus providing the number of milestones actually completed during the reporting period. The pseudo-code for this calculation is:

If the finish date is in the reporting period and percent complete is equal to 100, then determine the number of tasks actually completed.

The query was then reset to include only milestones that were executed after the reporting period. The data returned from this query was analyzed to determine if future tasks had been completed. To calculate future milestones completed during the evaluation period, *Mf*, the percent complete and the start date elements were then used to determine if future efforts had been completed during the reporting period. Additional filters must be included to exempt future tasks completed in prior reporting periods. The pseudo-code for this calculation is:

If percent complete is equal to 100 and start date is greater than last date of reporting period and not used in prior reports then determine the number of future milestones completed.

The following seven steps are used to calculate the inputs to calculate the MPI.

1 . Incomplete Milestones for this period ($IM\delta$)

$IM\delta$ = Actual milestones completed minus the planned milestones

$$IM\delta = \text{Ma-Mp} \tag{3.4}$$

Alternately, $IM\delta$ can be calculated as follows:

If finish date is less than or equal to last date of reporting period and percent complete is less than 100 then count this milestone as delinquent and incomplete.

2 . The Milestone total of actual and future milestones completed during the evaluation period (Mt)

Mt = Milestones Actual + Milestones Future

$$Mt = Ma + Mf \tag{3.5}$$

3 . Sum of the incomplete milestones from this reporting period and prior periods ($SIM\delta$)

$$SIM\delta = \mathrm{Sum}(IM\delta) \tag{3.6}$$

4 . Total milestones planned for completion during the evaluation period (MTp)

MTp = Milestones planned + Sum of the incomplete milestones from prior periods

$$MTp = Mp + SIM\delta \tag{3.7}$$

5 . Actual Milestones completed ratio ($AM\rho$)

$AM\rho$ = Actual milestones completed divided by the total planned milestones

$$AM\rho = Ma/MTp \tag{3.8}$$

6 . Future milestones completed ratio ($FM\rho$)

$FM\rho$ = Future milestones completed divided by sum of the incomplete milestones

$$FM\rho = Mf/SIM\delta \tag{3.9}$$

7 . Incomplete Milestones ratio ($IM\rho$)

$IM\rho$ = Sum of the incomplete milestones divided by total planned milestones

$$IM\rho = SIM\delta/MTp \tag{3.10}$$

The MPI, then, can be calculated as follows,

$$MPI = [1+(IM\rho/(AM\rho - FM\rho))] \tag{3.11}$$

The MPI allows visibility into the work that was planned but not accomplished and gives credit for future work executed early. The equation follows the scaling that currently is used in calculating SPI and CPI. Anything below 1.0 is poor execution, while anything above is considered good execution.

While the example used in this research is based on the monthly milestone reporting data, the MPI indicator is scalable and not dependent on the reporting period. The data analysis and results for this research project are developed from actual data derived from data sets provided monthly by the vendor.

3.8 RESOURCE ALLOCATION INDICATOR DEVELOPMENT

If milestones are not being met, one or more conditions may be affecting the situation. One condition that may be affecting the successful completion of the tasks under each milestone is the inappropriate or ineffective application of resources.

Management of resources in complex technical programs is problematic, especially in organizations which rely on the availability of a pool of talent to provide the appropriate subject matter experts to programs.

The difficulty in managing this situation centers on accessibility to appropriate talent when the schedule demands availability. Even the generalized reporting of resource availability provides significant insight to the complex management problems in coordinating the availability of staff. The proposed Resource Allocation Indicator (RAI), equation 3.12, can be calculated as follows:

$$RAI = \frac{Actual\ Staff - ETC\ Staff}{BCWS\ Staff} \tag{3.12}$$

- *Actual Staff* is the number of staff associated with the program during the reporting period;
- *ETC Staff* is the planned number of staff associated with the program during the reporting period; and
- *BWCS Staff* is the budged number of staff associated with the program during the reporting period.

As the RAI increases above or decreases below one (1.0), program management should take notice and investigate the milestone completion indicators and compare them to the allocation of specific resources. While the example explored in this project is based on the program staffing data, detailed analysis at the milestone and task level may be warranted. This indicator is scalable and not dependent on the reporting period. The following section will demonstrate results achieved from applying the proposed MPI and RAI metrics to the program under study.

CHAPTER 4

RESULTS

4.1 INTRODUCTION

Given that this doctoral project is focused on the solution of a practical problem, it is desirable that the findings from this research may be applicable to similar engineering efforts in the future. Generalizability, a component of research validity, is one of the important concepts for the foundation of any research effort. The author will discuss results which contain context and insights to ensure the generalizability of the results from this research to typical engineering projects.

4.2 PROGRAM SCHEDULE DATA ANALYSIS

If EVM is reported on a monthly basis, then many short duration tasks and milestones may not be met or identified as critical. This is an indication that the vendor may not have an adequate reporting mechanism or earning rule for the reporting of progress of tasks. In this case, future tasks and milestones may be executed to mask the fact that priority task and milestones were not being completed. Additionally, short duration tasks and milestones are difficult to analyze in long EVM reporting cycles. Therefore, an enhanced progress measure is needed which is more difficult to manipulate. Thus, the MPI and RAI provide insights for program management decisions to investigate progress at a finer granularity at the task level.

The relationship of resource staffing and milestone completion adds visibility on a periodic basis to indicate the successful completion of individual milestones. This analysis indicated that the program was executing ahead of schedule. However, the critical milestone report indicated that the schedule was slipping on a daily basis. This evaluation may be used to prompt inquiry as to why critical tasks are not being completed and may provide insight to help answer the question of why priority tasks are not being completed on time.

Evaluations where the measure of progress is "milestones completed" rely on the reporting of planned effort, actual effort and future effort executed before it was scheduled. These data were used as input to calculate the Incomplete Milestone Delta ($IM\delta$) and Sum of the Incomplete Milestone Delta ($SIM\delta$), as described in Chapter 3.

The Incomplete Milestone Delta and Sum of the Incomplete Milestone Delta, calculated from vendor reports, indicates that the program was executing ahead of schedule during the period from January 2010 to October 2010. The Incomplete Milestone Delta and Sum of the Incomplete Milestone Delta calculated from schedule analysis indicates that actual progress being made on the program was less than that reported by the vendor. During the same period, the program is actually under executing the baseline plan by hundreds of critical tasks.

A continual negative execution trend was exhibited throughout the program until May 2011. At this point, the program was seventy-three working days behind schedule. The vendor, in an effort to complete the program on time, implemented an extended work week to include Saturday and implemented a three-shift, twenty-four-hour-a-day operation.

The concept of true program health is defined as a quantitative measure of the difference between the program status that is presented in program management reports and the results that are derived after schedule analysis. Two comparative values must be calculated to provide validation of program health and progress. These two values are MPI Schedule (MPI_S) and MPI Reported (MPI_R). MPI_S is calculated after program schedules are analyzed and core MPI data has been derived. MPI_R should also be calculated if data reported in program management reviews contain anomalies such as those found during the research of this program.

Since program progress evaluation is dependent on both schedule derived data and vendor program management reported data, the comparison of the MPI_S and MPI_R data in Figure 10 provides a visual contrast between the two data sets. This visualization provides a capability to examine the differences between the actual state of the program and the state that was reported to the government program office by the vendor's program management.

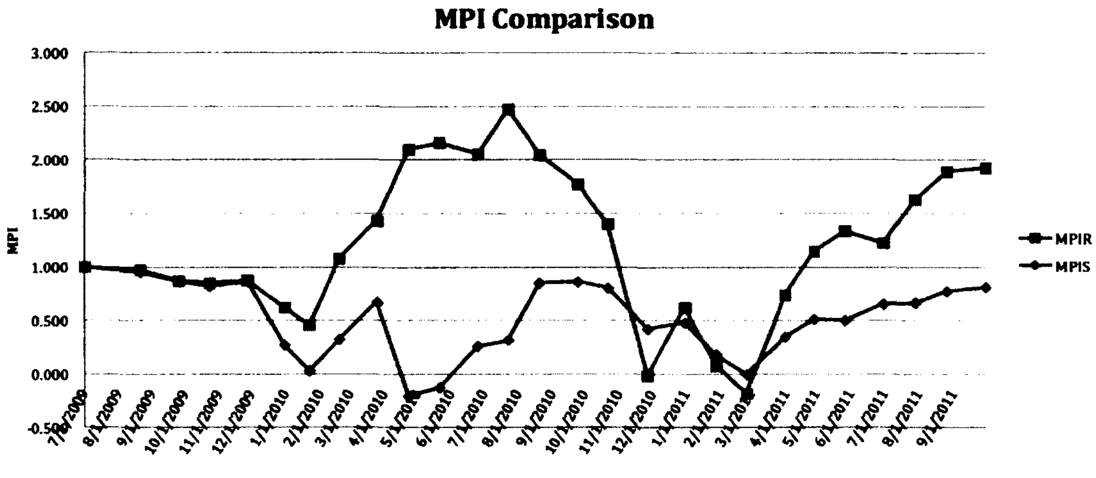

Figure 10. MPI_R / MPI_S Comparison.

The elevated SPI from the EVM reports and the calculation of MPI_R would lead government program management to believe that the program was healthy and ahead of schedule. However, the MPI_S based on schedule-derived data depicts a completely different picture. Almost from the beginning of the program, the MPI_S never approaches the optimum performance of 1.0 units at any time after initiation of the program in July 2009. The data set from the schedules that were evaluated indicate that the program was continuously underperforming, while the data set from the monthly program management reports show that much of the time the program was successfully meeting milestones and the program was moving forward. Examples of MPI calculations and additional graphs are included in Appendix B: MPI Calculations.

4.3 RESOURCE ANALYSIS

If milestones are not being met, one or more conditions may be affecting the situation. One condition that may be affecting the successful completion of the tasks under each milestone is the inappropriate or ineffective application of resources.

Management of resources on complex technical programs is problematic, especially in organizations which rely on the availability of a pool of talent to provide the appropriate subject matter experts to programs. The difficulty in managing this situation centers on accessibility to appropriate talent when the schedule demands availability. Even the generalized reporting of resource availability, as in Figure 11 (not included as a requirement for EVM), provides significant insight to the complex management problems in coordinating the availability of staff.

As the RAI increases above or decreases below the ideal value of one (1.0), program management should take notice and investigate the milestone completion indicators and compare them to the allocation of specific resources being used to execute tasks during the reporting period. While the example above is based on monthly program staffing data, detailed analysis at the task level may be warranted.

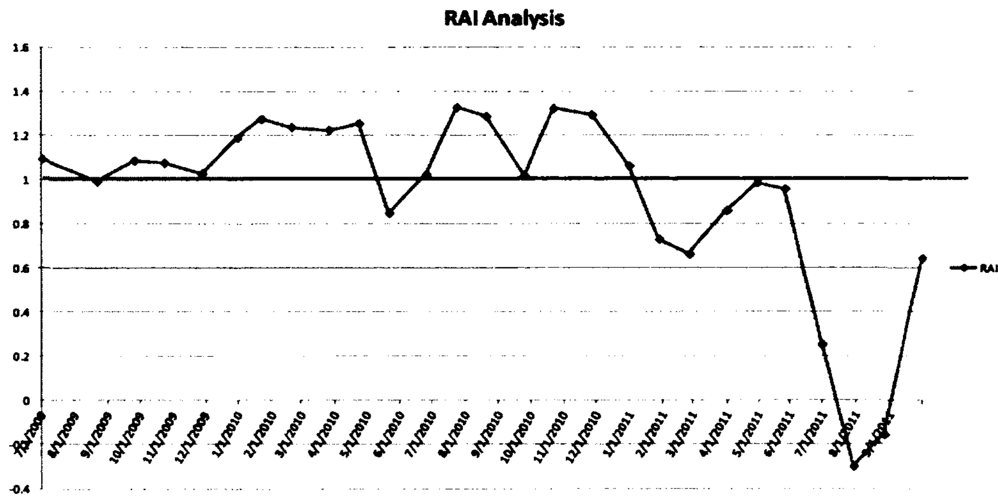

Figure 11. Resource Allocation Indicator.

4.4 PROGRAM STATUS ANALYSIS

These indicators are scalable and are not dependent on the reporting period. Therefore, analysis at various levels can also be accomplished. The MPI and the RAI provide insight into the progress of the program without biases. Figure 12 depicts the program status at a sampling rate with less granularity than those seen in Figure 10 which demonstrates the utility of the MPI and RAI in a project overview. Additionally, the SPI and CPI are graphed to provide a visual comparison against the ideal program status and the MPIs and RAI.

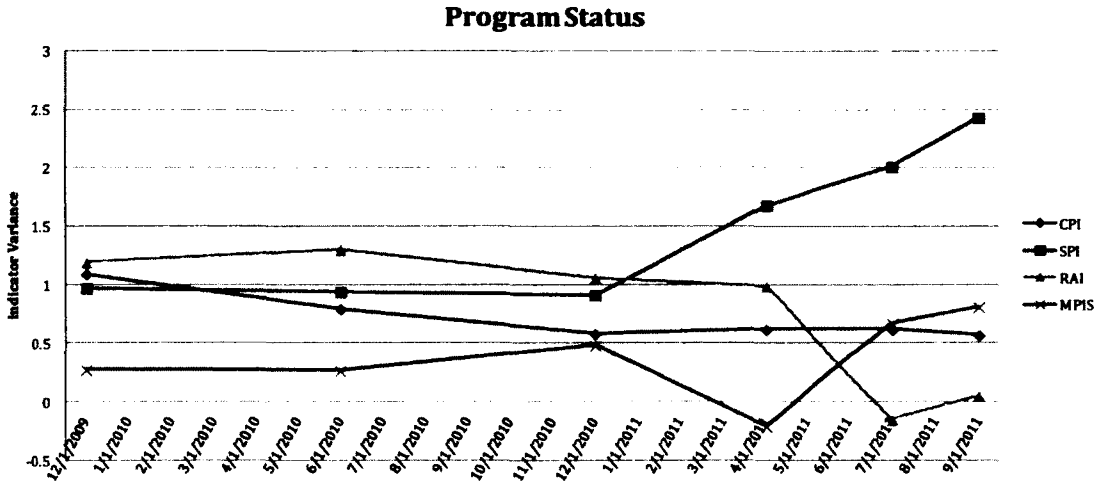

Figure 12. Program Status.

This analysis points out that the SPI shows that the program was performing within EVM tolerances. The MPIs indicates that critical milestones were not being executed, indicating that attention should have been applied as early as December 2009. This is further aggravated, given that the RAI indicates that resources were not being applied at the planned levels while critical milestones were not being executed.

Figure 13 and Figure 14 depict the true state of the program when program data was analyzed. Even though the SPI indicates that the program status is improving, the MPIs indicates that prior uncompleted milestones were still not being completed. Therefore, the health of the program with respect to successful completion is questionable. In response to the lack of progress, resources were applied to alleviate the schedule slips. In Figure 14, the RAI depicts this situation and shows that the allocation of resources is many times more than the planned resource allocation (thus a very low value is associated with RAI).

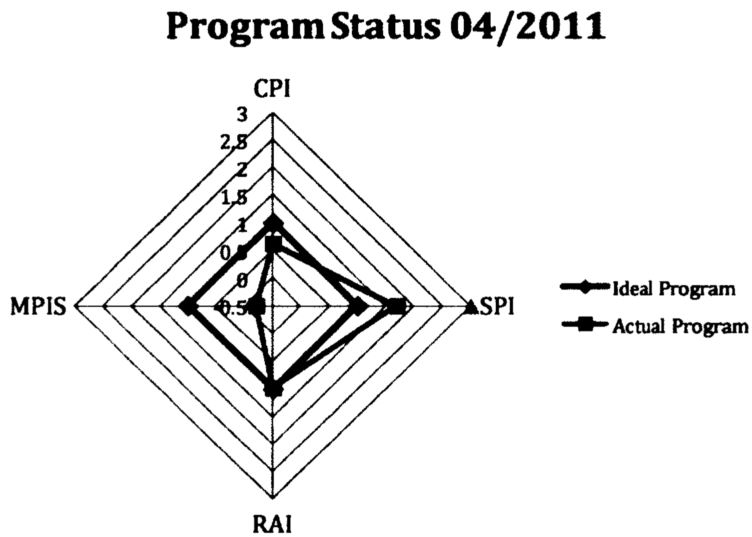

Figure 13. April 11 Enhanced EVM Program Status.

Specifically, Figure 13 indicates that the SPI was very positive and the program was reducing the slip in the schedule. These representations of SPI would lead the government program management team to believe that the program was in fact progressing on schedule. However, the MPIs indicates that the critical milestones from previous months were in fact not being completed.

It was not until September, (Figure 14. September 11 Enhanced EVM Program Status) that the MPIs started to indicate that the crucial milestones from prior months were being completed. This was at the expense of adding an additional 40-100+ people above the budgeted resources on the program to improve the program posture and reduce the number of incomplete critical milestones, thus causing the CPI to fall even further below the ideal value of 1.0.

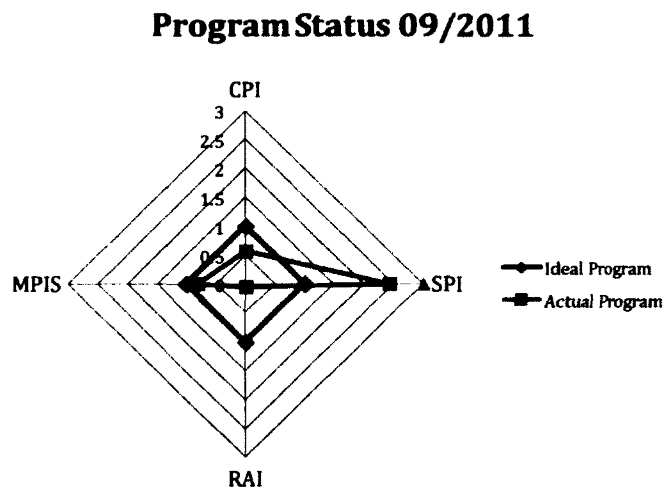

Figure 14. September 11 Enhanced EVM Program Status.

These examples were chosen to demonstrate that the EVM SPI did not correctly represent health of the program throughout the life of the contract. The MPIs provides a different representation of how the program was progressing and shows that the program execution plan in the schedule was not being followed. The MPIs indicates that the program started to reduce the number of incomplete milestones between April 2011 and September 2011. This was due to additional resources being allocated to the program (as indicated by a poor RAI), and to the extraordinary effort of the vendor's program teams working three shifts, six days a week. The author has witnessed this action on various technically complex programs which have experienced schedule delays. This appears to be the practice on many programs where technical and programmatic difficulties cause delays in the program. Additional examples of monthly status charts for the program can be found in Appendix C: Program Status with SPI, CPI, MPI, and RAI. The insights assembled from the results above are discussed in Chapter 5.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

EVM is utilized extensively in the reporting of execution of programs in the Department of Defense. Thus, EVM plays a significant role in managing programs and the analysis of the data that is derived from program management tools. The application of EVM in this program has not provided assistance to the vendor's program management to control cost, schedule or resource allocation. The utilization of EVM has been unable to help the vendor to meet the constraints of the contract and appears to have masked critical issues in the management of the program.

5.2 GENERALIZABILITY

5.2.1 Conclusions

Trochim and Donnelly (2007) indicate that generalizations are always a question of more or less similar conditions. Programs with characteristics and context that rank high along the gradient of similarity can be generalized with more confidence. In the case of this project, the ability to characterize each individual characteristic's axis of similarity is important. The axis of schedule length, program complexity, resourcing and staffing are the most problematic and subjective of the measures to develop a similarity profile for generalizability.

Measurements for the gradient of similarity axis may be calculated through the use of a simple one through ten (1-10) scaling mechanism. In an ideal program, the similarity value of five (5) should be considered average for all similarity axes. The axes of similarity for this research program that are considered average with a measure of five (5) include the twenty-four month duration of the program, or contract duration, EVMS Tailoring and IMS Reporting. Complexity is considered an eight (8) since the program experienced multiple technological issues where complicated subsystem development and defects were the reason for schedule delays. Staffing and resource availability was considered above average and is measured at eight (8), since additional personnel were required to execute critical events. The axis of type of contract is valued at ten (10) given that the firm fixed price contract is the most constrained type of contract with respect to cost, schedule and quality.

5.2.2 Recommendations

If heuristics and progress indicators are to be generalizable to other programs, the generalizability of environmental conditions for data analyses must include baseline metrics which are measurable and comparable to metrics available in similar programs. Data elements that were identified in the research program must be available for analysis in similar programs. Results (Figure 15) from the research program must be comparable to other programs with minimal ambiguity.

Therefore, the constraints and methods applied to the research project help to ensure that the findings from the collection of data and data analysis enhance the validity of the findings and overall generalizability of this research project effort.

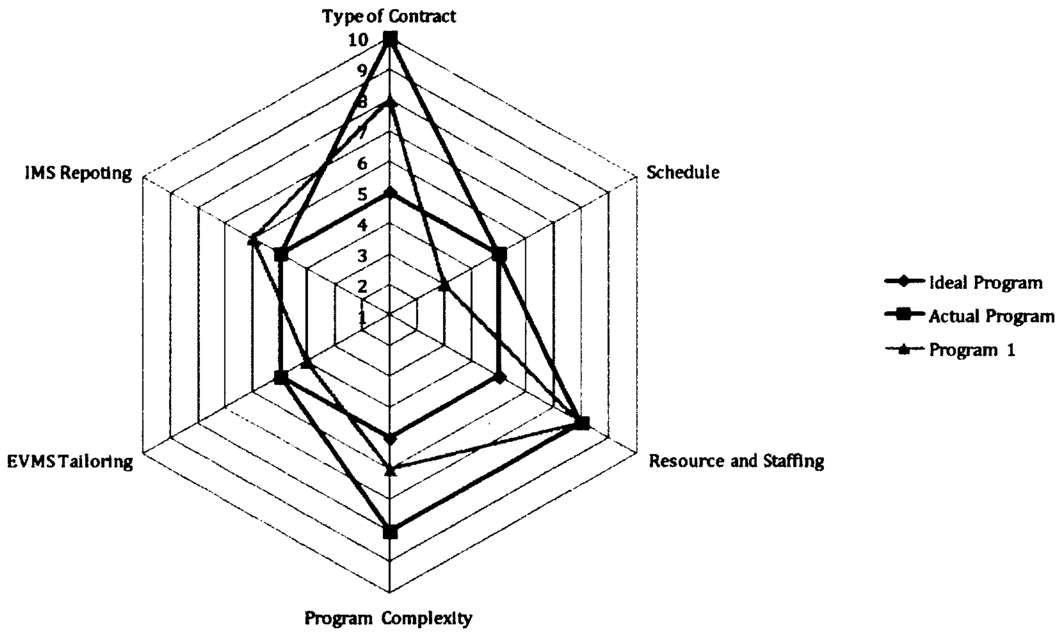

Figure 15. Gradient of Similarity.

Programs with characteristics and context that rank high along the gradient of similarity can be generalized with more confidence. In the case of this project, the ability to characterize each individual characteristic's axis of similarity is important.

With proximal similarity, generalizability contexts are used to develop a theory with respect to program characteristics that are similar to the program that is used as the baseline. When programs have been categorized with respect to specific characteristics and environmental context in terms of their relative similarities, the researcher can be reasonably sure that the findings from this research project can be applied to other programs that are to be evaluated.

5.3 IMPLEMENTATION OF ENHANCED EARNED VALUE MANAGEMENT

5.3.1 Conclusions

This research has culminated in the development of a model to reduce the magnitude of the weaknesses in EVM. This project evaluates the hypothesis of the research based on actual programmatic data for the analysis of the constraints of schedule, cost and quality in a restrictive contractual environment. This was accomplished through the development of programmatic progress indicators as postulated in the report from the Office of the Deputy Under Secretary of Defense (2009). These indicators provide an enhanced EVM (EEVM) construct which fills gaps identified at the highest levels of the Department of Defense.

The body of knowledge associated with Earned Value Management has been acknowledged as lacking several key attributes. One attribute that is lacking is a view into the quality of effort, in Figure 16 where non-critical tasks appear to have been performed to bolster the EVM SPI. EVM is exploitable and unfavorable findings from recent audits of DoD programs further indicate that EVM is not serving its intended function(USD AS Army & AS Air Force AT&L, 2008; USD AT&L, 2007).

There exists a need to continue development of EVM diagnostics tools to apply appropriate EVM information in acquisition decision-making to reduce the weakness exhibited in EVM such as those listed below.

Weaknesses include issues where:

- EVM measures may be static
- EVM is subject to manipulation of indicators
- EVM is subjective
- EVM data may not be directly comparable
- Lack of reliability of data source

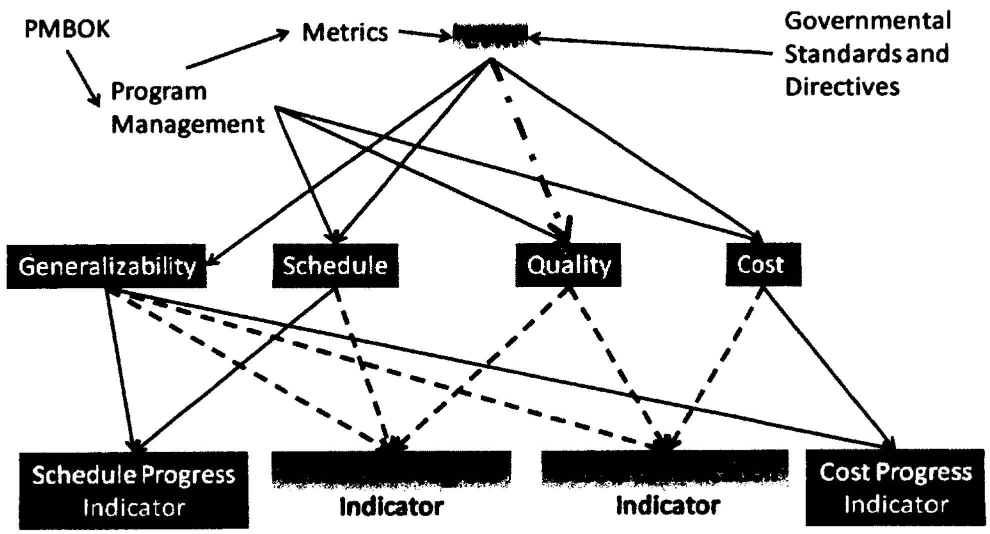

Figure 16. EVM Literature Gap.

Currently, EVM earning rules allow multiple interpretations of task and milestone completion. This condition allows invalid earning of future work to be claimed to maintain the SPI. Inconsistent and inappropriate implementation of earning rules does not address critical work versus non-critical work when earned value is claimed to reinforce the SPI, so that the schedule metrics indicate that the program is following the program plan. Metrics should be based on earning rules which address the cost of work planned, work performed and work not performed where methods identify critical versus non-critical efforts.

The development of quality measure heuristics such as the milestone progress indicator and resource allocation indicator will enhance the understanding of program progress in EVM reporting if implemented in a program where authenticated data is utilized to report program status.

In this research, the true progress of the program was inaccurately represented. This masking resulted, potentially, from future milestones being executed early and earned value being claimed against the planned earned value and actual costs, thus manipulating the SPI as seen in Figure 17. The differences between MPI_R and MPI_S (Figure 18) depict this masking effect.

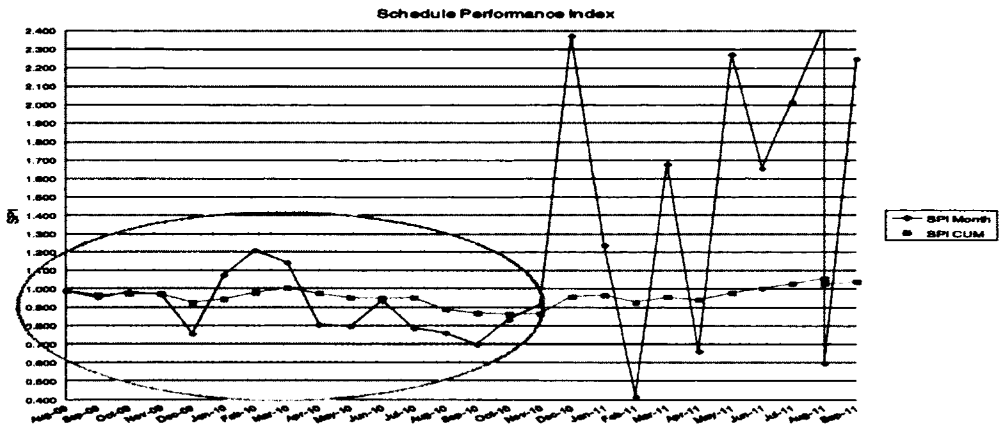

Figure 17. Program SPI.

5.3.2 Recommendations

Even with the guidance provided in standards and instructions that promulgate from the Department of Defense and the Department of Navy; utilization of this guidance does not necessarily mean that a program will be successful. So how does a project manager improve their chances of successfully managing a program? This can be accomplished through the inclusion of additional measures of program status that are derived from the data produced by the project, such as performance indicators.

Inaccuracies in data and inappropriate tailoring of earning rules indicate that the measurement of quality lacks rigor with respect to measuring progress in this program. It is very important that the MPI_R and MPI_S be calculated independently to ensure that reported data portray the accurate health of the program, such as that depicted in Figure 18. One of the ways to improve the execution of technically complex programs is through the use of measures of performance such as those used in EEVM.

EEVM should utilize the same constructs of EVM SPI and CPI where progress indicator values equal to one (1) mean that program performance is satisfactory (performing on budget and on schedule). EVM and EEVM progress indicator values have the following definitions.

The EVM progress indicator SPI values indicate:

< 1 means that the completion of planned effort is behind the plan (poor);
= 1 means that the completion of planned effort is right on plan (satisfactory);
> 1 means that the completion of planned effort is ahead of plan (good).

The EVM progress indicator CPI has a similar meaning where:

< 1 means that the cost of completing the work is higher than planned (poor);
= 1 means that the cost of completing the work is right on plan (satisfactory);
> 1 means that the cost of completing the work is less than planned (good or sometimes bad).

The EEVM progress indicator MPI has a similar meaning where:

< 1 means that the completion of planned effort is behind the plan (poor);
= 1 means that the completion of planned effort is right on plan (satisfactory);
> 1 means that the completion of planned effort is ahead of plan (good).

The EEVM progress indicator RAI has a similar meaning where:

< 1 means that resources required to complete the work is higher than planned (poor);
= 1 means that resources required to complete is right on plan (satisfactory);
> 1 means that resources required to complete is less than planned (good or sometimes bad). (Bad if inadequate resource allocation causes the MPI to fall below 1.0)

Data and calculations required for enhanced EVM as in Figure 18 are outlined below. The following inputs are used to calculate the metrics for EEVM.

- Planned milestones for completion during the evaluation period - Mp

- Actual milestones completed during the evaluation period - Ma
- Future milestone completed during the evaluation period – Mf

The following equations are used to calculate the metrics for EEVM.

1. Milestone total actual and future completed during the evaluation period - Mt= Ma+ Mf
2. Incomplete Milestones for this period - IMδ=Ma-Mp
3. Sum of the missed milestones from prior periods - SIMδ=Sum(IMδ)
4. Total milestones planned for completion during the evaluation period - MTp= Mp+ SIMδ
5. Actual Milestones completed ratio - AMρ= Ma/MTp
6. Future Milestones completed ratio - FMρ= Mf/SIMδ
7. Incomplete Milestones ratio - IMρ= SIMδ/MTp

$$MPI=[1+(IM\rho/(AM\rho- FM\rho))] \tag{3.11}$$

The MPI_R (Figure 18) depicts data take from vendor reports developed by the vendor's program management. The MPI_S (Figure 18) portrays the actual progress of the program from data derived from schedule analysis.

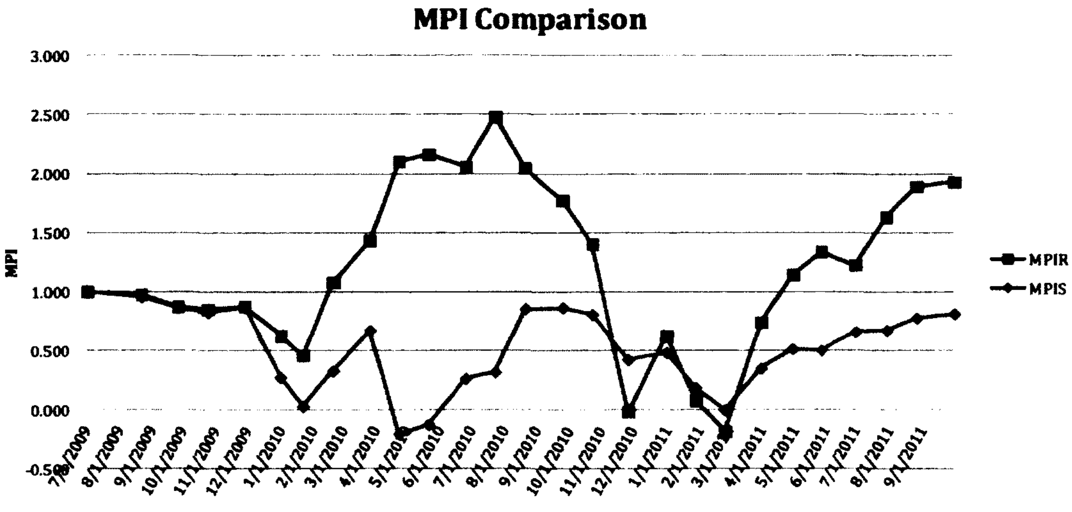

Figure 18. MPI_S Versus MPI_R.

An artifact from the calculations for MPI_S and MPI_R indicate that the program MPI_S and MPI_R appear to be in sync from July 2009 to December 2009 (Figure 18). Then the MPI_R deviates from the MPI_S indicating that EVM reported data may be inaccurate. Performance indicators in EEVM, such as MPI, augment the disclosure of inaccuracies occurring in reporting artifacts such as those derived from monthly vendor reported EVM data.

In combination with the milestone progress indicator, this research included the development of a resource allocation indicator to be used in conjunction with the milestone progress indicator as seen in Figure 19. The Resource Allocation Indicator is calculated by using equation 3.12.

In planning to use EEVM, first look for inaccuracies in the data. To provide a multi-axis analysis, use schedule element data and vendor reports to calculate MPI_S and MPI_R to determine if reported data are accurate.

Calculate the RAI to determine if staffing is adequate. Evaluate MPI_S and RAI to determine the health of the program. If MPI_S is below 1.0 and RAI is above 1.0 then the program is understaffed and not executing planned critical milestones. This condition existed in the program under study during multiple periods of analysis. The program was understaffed for the first half of the program thus exhibiting a RAI > 1.0 and $MPI_S < 1.0$. From December 2010 on, the program required additional staff to make the first article deliveries thus driving the RAI into a negative trend.

One of the most important periods in which this condition occurred was at the beginning of the program: 8/1/2009 through 2/1/2010. This is visually depicted in Figure 19, where the MPI continues a downward trend during the beginning of the program. Finally, to meet the contract delivery date, the vendor applied significant resources as can be seen during the period from 6/1/2011 through 8/1/2011. The vendor allocated between 50-100 additional people per week to catch the program up and make the first article deliveries. This influx of resources improved the MPI_S and allowed the vendor to deliver the system on schedule at a significant increase in labor cost.

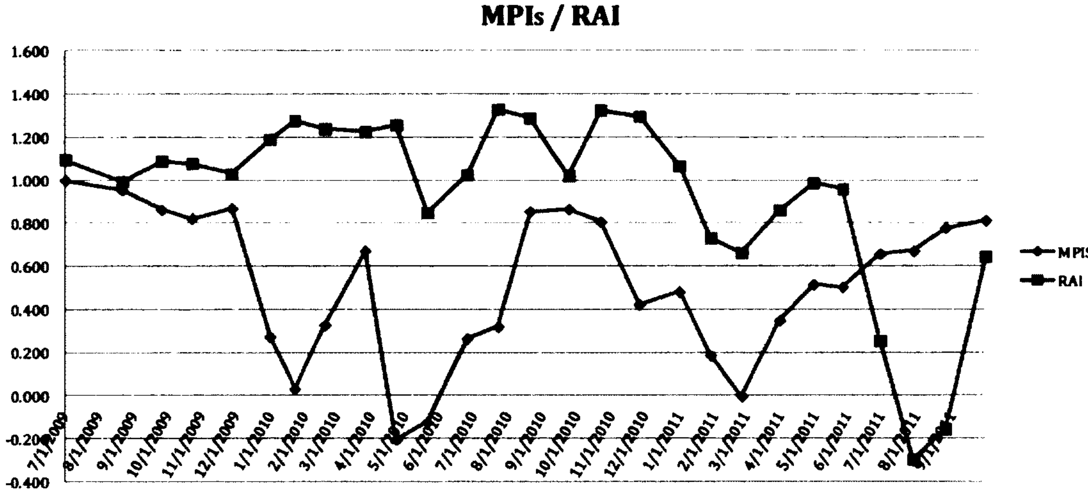

Figure 19. MPIs and RAI Evaluation.

When comparing this program to an ideal program, the graphs in Figure 20 and Figure 21 depict an alarming situation. Monthly samples of program status using the four indicators depict that:

1. SPI - Schedule Progress Indicator shows that the program is healthy and floats around the ideal value of 1.0

2. CPI - Cost Progress Indicator depicts that the program over-expends the budget and never recovers.

3. RAI - Resource Allocation Indicator depicts that the vendor is understaffed until 2011

4. MPI - Milestone Progress Indicator illustrates that technical progress is behind throughout the execution of the program.

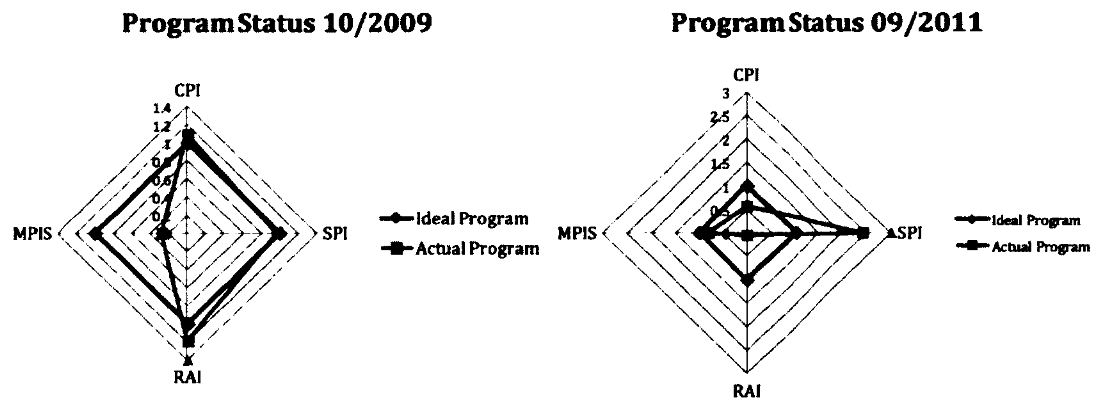

Figure 20. Beginning and End EEVM.

By combining EVM and EEVM, the following program status charts (Figure 21) were developed and provide post execution indications that the program was failing since the start of the contract. Thus EVM and EEVM information should be used jointly to provide adequate insight into program progress and status.

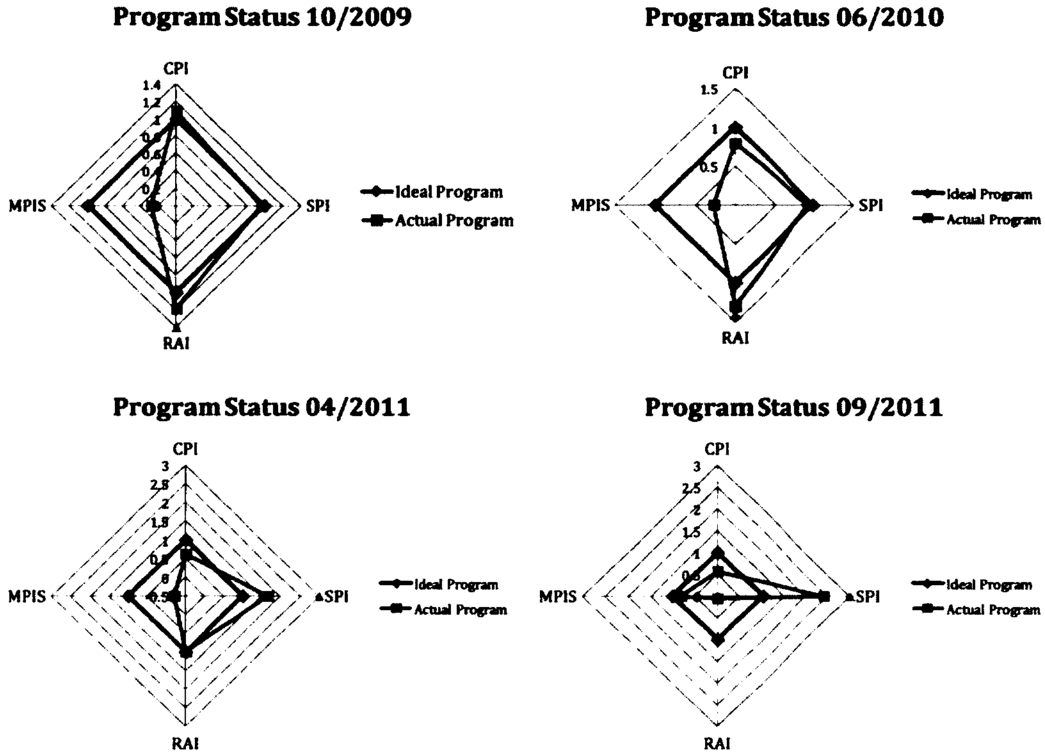

Figure 21. Research Program EEVM Analysis.

5.3.2.1 EEVM Variance Reporting

ANSI Standard 748 requires at least monthly analysis and reporting for significant cost variances (CV) and schedule variances (SV) as identified in a Booz Allen Hamilton brief for the Department of Energy (2003). In an Earned Value Management System, a threshold may be set for a positive or negative schedule variance or cost variance. Significant variances are objectively determined through the use of contractual and management thresholds.

Contractual thresholds are mutually agreed upon deviations beyond which a customer must be informed about schedule or cost variances. Management thresholds are typically more restrictive than contractual thresholds and are used in a similar fashion. Management thresholds are used for internal management purposes and can be used as an early warning where programs are trending toward exceeding a contractual threshold.

The Booz Allen Hamilton (2003) brief identifies baseline variance thresholds, where the size and complexity of the project determines the variance levels to elicit impromptu status reporting. Individual government agencies will set variance thresholds at diverse levels, but most set contract variance levels between ±7% to 10%. This means that a SPI or CPI of 0.93-1.07 or 0.90 - 1.1 will require a variance analysis report to explain what is occurring on the program. The use of EVM (SPI and CPI) and EEVM (MPI and RIA) program management thresholds that are more restrictive. Variances of ±3% to 5%, are recommended to prevent contractual threshold violations. These more restrictive thresholds allow program management time to investigate and correct the program management variance violations before contract violations occur.

5.4 PROGRAM SCHEDULE DATA ANALYSIS

5.4.1 Conclusions

The progress indicators developed during this research allow the measurement of program health and maturity. The progress indicators offer enhancements to provide quantifiable measures of progress. Due to the extraordinary overruns and delays associated with this program, effective implementation of program management practices appear to be lacking. This research project has utilized the analysis of EVM data as a foundation for determining why program execution faltered.

One finding of the investigation is that program management tools were not coupled. The schedule was kept in Microsoft Project, staffing data was kept in Excel, and defect information was kept in Clearquest. While these issues are not insurmountable, they potentially add to data reporting errors, where segregated program data could not provide sufficient insight to keep the program constraints successfully in check. The inclusion of resource staffing data applied at the task level in MS Project could have provided a straightforward indicator that resources were not being applied appropriately.

An example of this lack of coupling between the program data elements was found in weekly progress reports where historical program status data changed (see, Figure 22 below and Appendix B: MPI Calculations, Figure B 1). These discrepancies were found during program status report analysis and the analysis of program schedules.

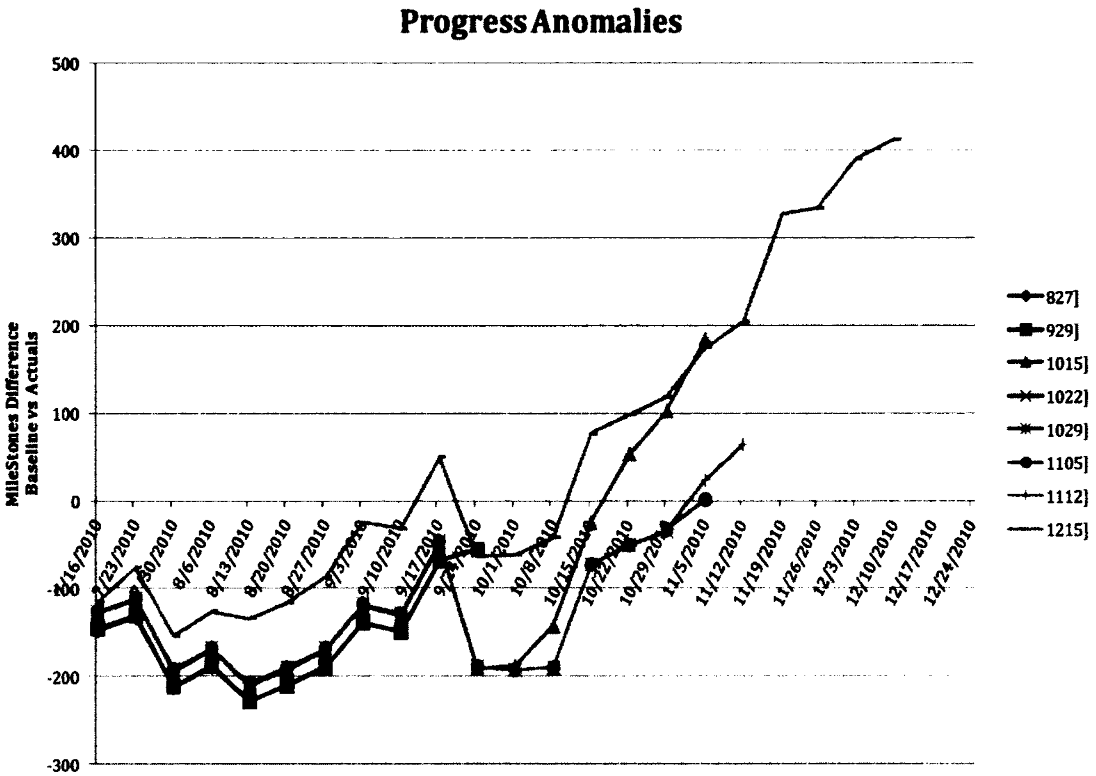

Figure 22. Historical Report Analysis.

The data analysis found that non-critical tasks were added to the schedule in July 2010. Figure 23 highlights this situation where the count of tasks increased from approximately 3600 to 7600, finally reaching over 9000 tasks. These anomalies prompted the author to investigate the schedules in greater detail to determine if other issues existed. Many non-critical tasks were claimed as completed immediately after inclusion into the schedule, thus bolstering the SPI.

Additionally, this investigation found that critical tasks were not being completed and future tasks were being executed thus augmenting the EVM SPI. This situation appears to be problematic and is potentially a factor in the program's chaotic and deteriorating EVM state.

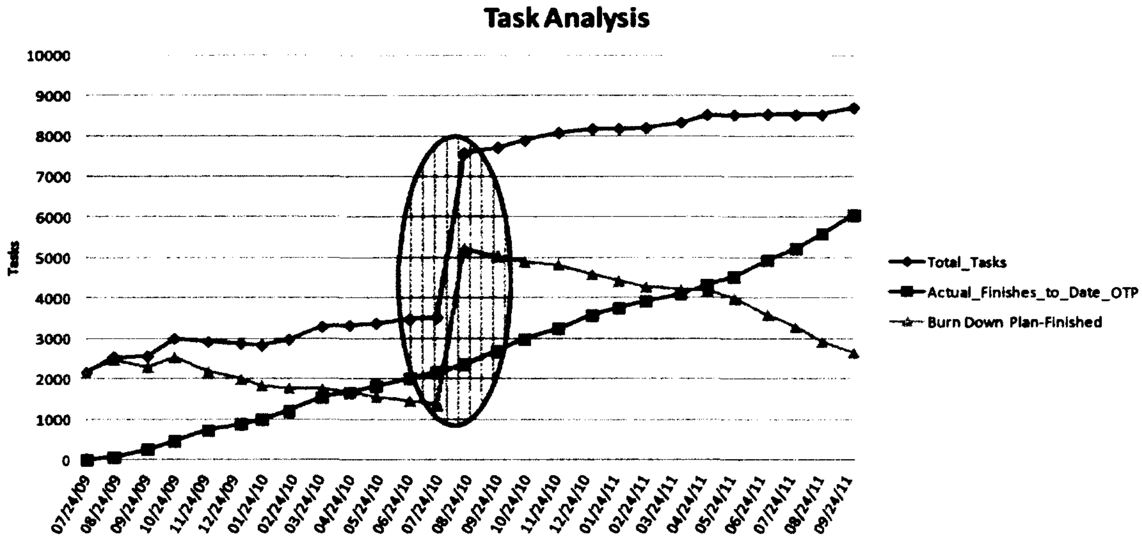

Figure 23. Program Schedule Task Counts.

5.4.2 Recommendations

To understand the program scheduling delays and associated issues, we need to look at the data from the program and address the findings and issues such as those exhibited by the EVM CPI and SPI.

Progress anomalies where historical data changes should be addressed immediately as discrepancies are found in the data. Evaluation of allocated resources, the count of completed milestones, and the count of milestones and tasks in the program schedule should be calculated to add insight to the EVM SPI and CPI. This should be performed on a monthly basis since short duration tasks and milestones are difficult to analyze in long EVM reporting cycles.

If EVM is reported on a monthly basis, then many short duration task and milestones may not be completed or identified as critical. This may indicate that the vendor does not have an adequate reporting mechanism (earning rule) for the reporting of progress of tasks. In this program it appears that supplementary future task and milestones have been executed thus screening the fact that priority task and milestones were not being met. Thus progress indicators such as the MPI and RAI would provide significant insight to this situation.

One finding of the research is that program management tools were not coupled. While these issues are not insurmountable, they potentially add to data reporting errors, where segregated program data would not provide sufficient insight to keep the program constraints successfully in check. This situation requires that the author make the following recommendations that program managers should consider:

1. Tools should include a coupled interface such that data can be validated automatically.
2. Ensure that each task has work hours associated with it.

3. Ensure that task duration estimates correspond to the levels of effort required to complete the work, (i.e. resource allocation matches the amount of work expected during the execution of the task).
4. Ensure the status of work completed matches the level of execution expected at the date that status is provided (i.e. resources are actually applied to the tasks where the status indicates progress).
5. Resources (team members) should be charging against the actual work tasks where effort is expended.

These recommendations may require that resource allocation measures be applied on a task by task basis to ensure that planned efforts take into consideration that complex programs require constant monitoring.

5.5 COST

5.5.1 Conclusions

While much of the effort of this project has focused on the management of milestones, schedule issues and resource allocation, cost should also be discussed to blend the elements of EVM. Figure 24 depicts conditions that are inherent in fixed price contracts. In a Firm Fixed Price contract, the vendor is able to earn varying levels of profit based on proper management of costs. This ability to earn profit is countered with the risk that the vendor may also be required to supplement the total funds applied by the government thus making no profit.

In business, as in the Department of Defense, variations in schedule and resources affect the cost of a program. In the majority of programs, the Department of Defense must provide supplemental funding when program cost overruns are experienced. In this case, the vendor was solely responsible for the cost overruns associated with schedule delays and resource variations.

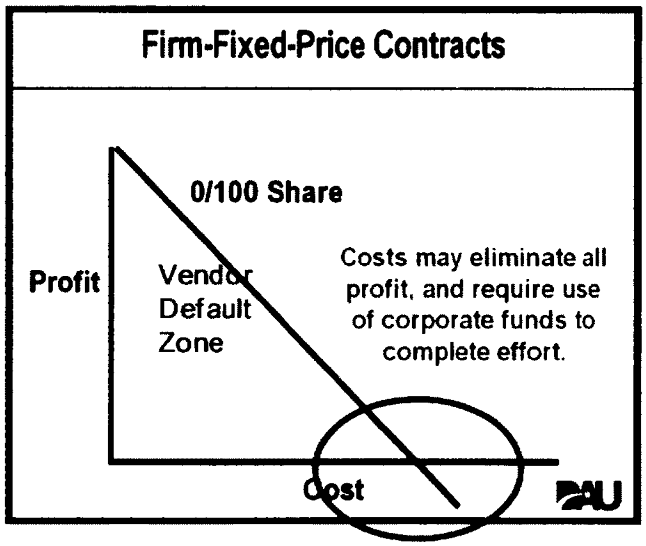

Figure 24. Profit Versus Cost Graph Adapted from DAU (2012a).

The EVM cost progress indicator metrics point out that the program has been in an over-expended state almost from the beginning of the contract (Figure 25). The reported cost overruns indicate that the program was over spending by twenty percent to twenty-five percent.

Data and calculations (Appendix D: EVM Calculation Examples) derived from untreated program management data (April and September 2011), provide an alternate account which illustrates the extent of overruns for elements of the WBS. This evaluation used the original budgeted cost of work scheduled (BCWS) from the baseline budget for which the contract was awarded and estimates to complete (ETC) calculated at later dates, when actual costs were used to provide revised cost. The analyses from these calculations indicate that the program may in fact have been over-expended by as much as fifty-six percent.

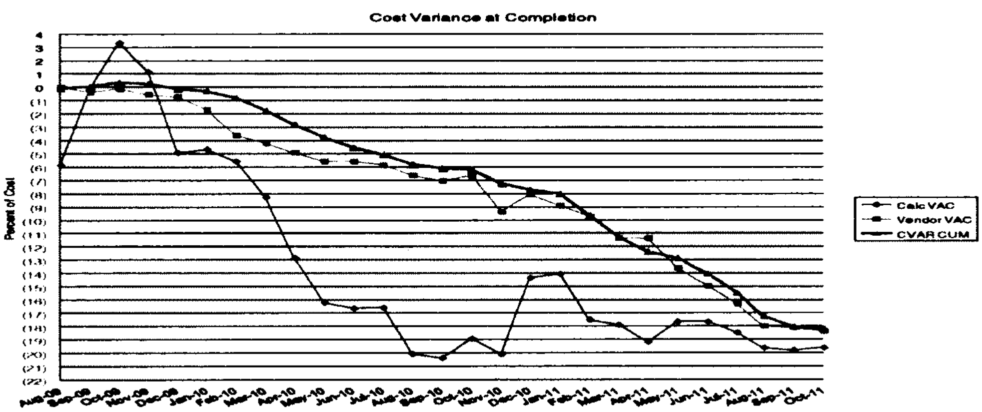

Figure 25. Contractor and DoD Evaluations of Cost Variances.

5.5.2 Recommendations

Schedule delays and resource allocation issues have driven the vendor to supplement the base cost of the contract. Most vendors could never sustain this level of financial depletion and would have terminated the program. Future work should incorporate advanced cost indicators in order to prevent early project termination. Additional measures should be developed in the future to evaluate whether a vendor has the appropriate mix and quantity of staff to develop a reasonable program cost baseline for effective and meaningful program management.

During the execution of the program, the schedule suffered a slip of approximately seventy-three days (Vendor report from 15 May 2011). To alleviate this condition, the vendor applied additional resources so that members of the program team were working multiple shifts up to six days a week with a target of fifty hours a week per person. The additional resources, along with the requirement to reduce the schedule slip, affected the overall cost of the program. Had the milestone progress indicator been available to program management at the beginning of the program, appropriate levels of resources could have been applied over longer periods to improve the progress of the program.

Had the resource allocation indicator been available to the vendor at the beginning of the program, analysis of the relationships between milestone completion, and resource allocation could have provided additional insight into the lack of progress associated with inconsistent reporting of milestone completions (elevated SPI) and the inappropriate allocation of resources.

The value of this analysis comes from the potential identification of out of sequence task execution which masked the condition where priority tasks were not being accomplished. Therefore, the program status constructs of milestone progress indicator and resource allocation indicator developed in this research should be included as part of the standard for reporting of EVM program status.

5.6 FUTURE EFFORTS

As indicated in the literature review, there are additional research topics and methods which could be applied to further this research. These include:

1. Research into fuzzy data clustering to address planning deficiencies such as those found in this research.
2. Baseline schedules should be investigated through the use of absorbing Markov analysis to address planning deficiencies such as subject matter expert biases.
3. Baseline schedules should be investigated through the use of fuzzy logic analysis to address planning deficiencies such as subject matter expert biases and program complexity.

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APPENDICES

APPENDIX A. DATA ELEMENT LIST

Actual Cost Of Work Performed
Budgeted Cost Of Work Scheduled
Cost Performance Index
Schedule Performance Index
Start Date Of The Task, Milestone
Finish Date Of The Task, Milestone
Estimate At Completion
Percent Of Work Completed
Staffing Levels
Staffing Types
Work Hours Associated With Task, Milestone

APPENDIX B. MPI CALCULATIONS

The following figure (Figure B 1. Corrupt Historical Reports.), depicts one of the anomalies that prompted the author to investigate the reported data at a higher granularity and to further analyze the results calculated for the MPI and RAI.

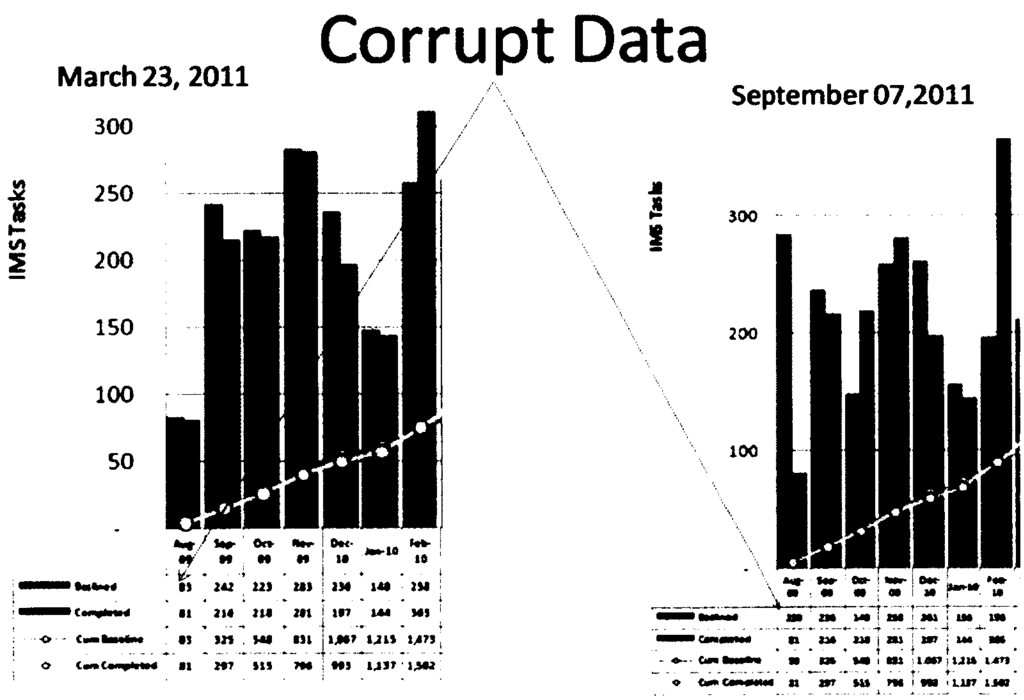


Figure B 1. Corrupt Historical Reports.

The evaluation of the progress where the measure of progress is "milestones completed" relies on the reporting of planned effort, actual effort and future effort executed before it was scheduled. This is graphically depicted in Figure B 2. This data was used as input to calculate the IMδ and SIMδ as described in Chapter 3.

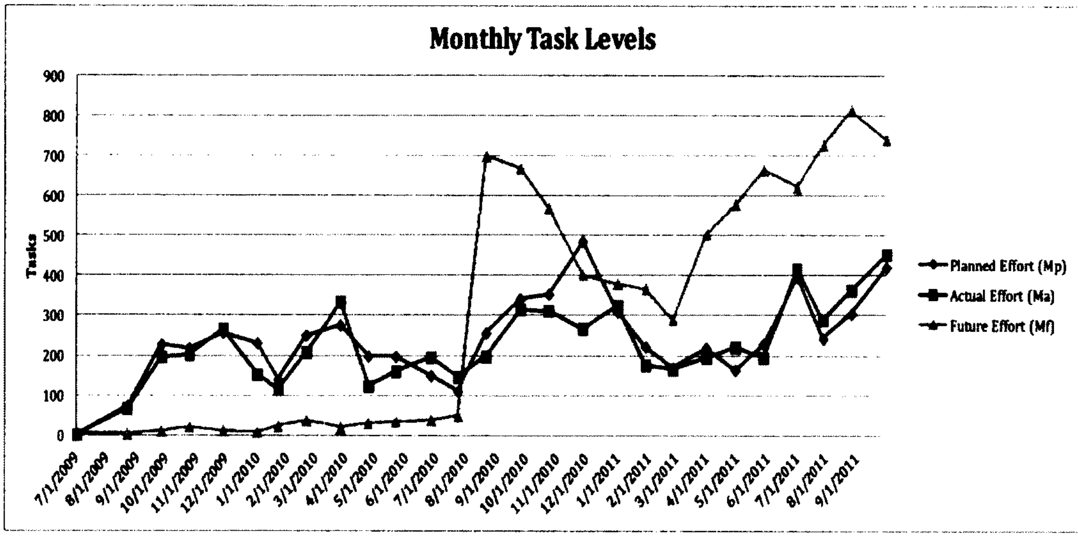


Figure B 2. Monthly Schedule Evaluation of Effort.

Utilizing input data such as the data depicted in evaluation of IMδ and SIMδ as represent as in Figure B 3 the RPD line depicts the status of the program when reports from the vendor program management were analyzed. The evaluation of reported data in Figure B 3, indicates that the program is executing ahead of schedule during the period from February 2010 to October 2010.

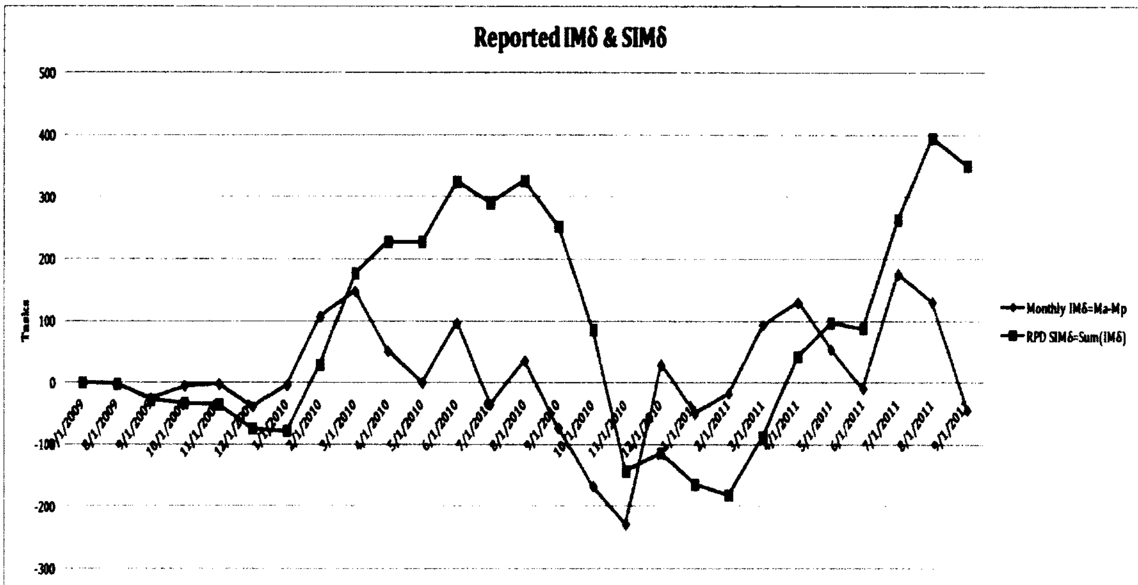


Figure B 3. IMδ & SIMδ Evaluation of Vendor Monthly Progress Reports.

During the period between February 2010 and October 2010, as can be seen from data derived from the monthly schedules, the SCD line in Figure B 4 indicates that the program is actually under executing the baseline plan by hundreds of critical tasks.

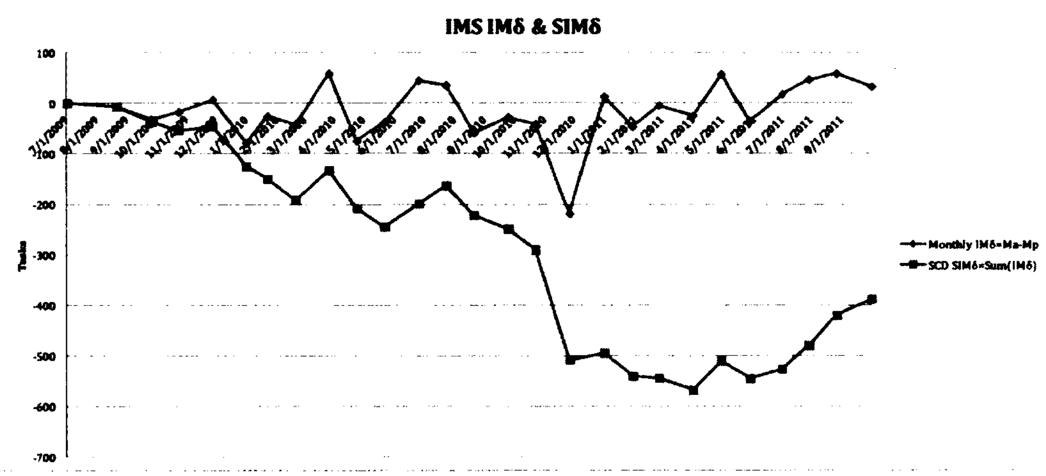


Figure B 4. IMδ & SIMδ Evaluation from Monthly Schedule.

Figure B 5 shows that the program was falling behind in executing milestones that were scheduled each month. The inability to complete scheduled milestones is evident in the IMδ trend in Figure B 5. This trend follows a continual negative slope throughout the program until May 2011. At this point, the program was sixty-nine working days behind schedule. The vendor, in an effort to complete the program on time, implemented an extended work week to include Saturday and implemented a three shift twenty-four hour a day operation. The milestone progress indicator and the milestones completed delta provide insight into the progress of the program without external influences or biases.

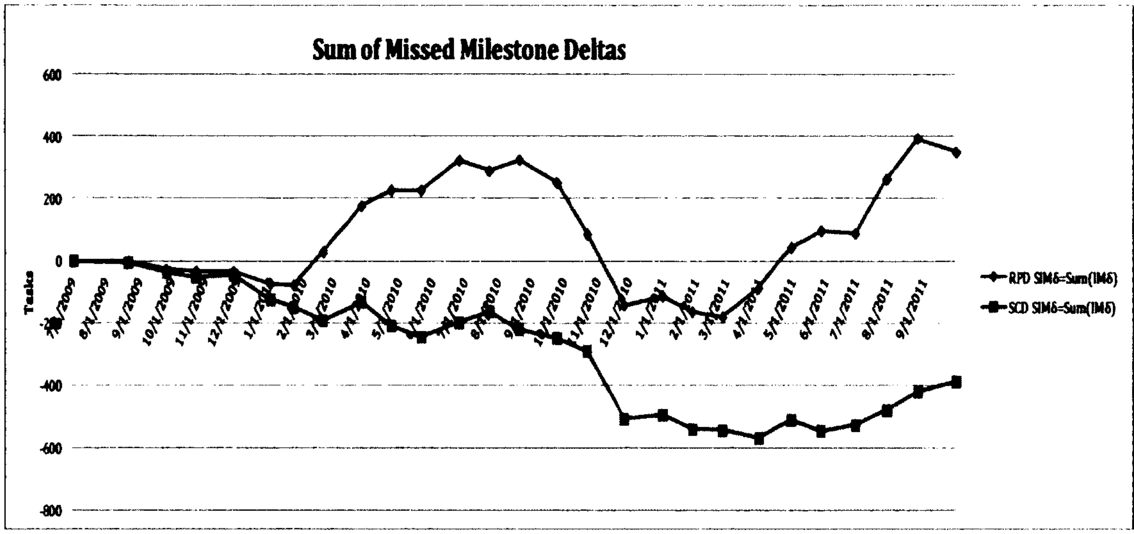


Figure B 5. Reported & IMS Incomplete Effort.

The following tables, Table B1 and Table B2, were used to calculate the information depicted in the graphs above.

Data from Monthly Reports/ Unknown Future Task	Planned Effort (Mp)	Actual Effort (Ma)	Future Effort (Mf)	Total Effort Mt=Ma+ Mf	Monthly IMδ=Ma- Mp	RPD SIMδ=Su m(IMδ)	MTp=Mp +SIMδ	AMp=Ma /MTp	FMp=Mf/ SIMδ	IMp=SIM δ/MTp	AMp-FMp	MPIR
7/1/2009	1	1	0	1	0	0	1	1.000	0.000	0.000	1.000	1.000
8/1/2009	83	81	0	81	-2	-2	83	0.976	0.000	-0.024	0.976	0.975
9/1/2009	242	216	0	216	-26	-28	244	0.885	0.000	-0.115	0.885	0.870
10/1/2009	223	218	0	218	-5	-33	251	0.869	0.000	-0.131	0.869	0.849
11/1/2009	283	281	0	281	-2	-35	316	0.889	0.000	-0.111	0.889	0.875
12/1/2009	236	197	0	197	-39	-74	271	0.727	0.000	-0.273	0.727	0.624
1/1/2010	148	144	0	144	-4	-78	222	0.649	0.000	-0.351	0.649	0.458
2/1/2010	258	365	0	365	107	29	336	1.086	0.000	0.086	1.086	1.079
3/1/2010	261	409	0	409	148	177	232	1.763	0.000	0.763	1.763	1.433
4/1/2010	156	207	0	207	51	228	-21	-9.857	0.000	-10.857	-9.857	2.101
5/1/2010	196	196	0	196	0	228	-32	-6.125	0.000	-7.125	-6.125	2.163
6/1/2010	211	308	0	308	97	325	-17	-18.118	0.000	-19.118	-18.118	2.055
7/1/2010	231	196	0	196	-35	290	-94	-2.085	0.000	-3.085	-2.085	2.480
8/1/2010	275	311	0	311	36	326	-15	-20.733	0.000	-21.733	-20.733	2.048
9/1/2010	400	327	0	327	-73	253	74	4.419	0.000	3.419	4.419	1.774
10/1/2010	380	213	0	213	-167	86	127	1.677	0.000	0.677	1.677	1.404
11/1/2010	370	141	0	141	-229	-143	284	0.496	0.000	-0.504	0.496	-0.014
12/1/2010	274	303	0	303	29	-114	417	0.727	0.000	-0.273	0.727	0.624
1/1/2011	228	178	0	178	-50	-164	342	0.520	0.000	-0.480	0.520	0.079
2/1/2011	170	153	0	153	-17	-181	334	0.458	0.000	-0.542	0.458	-0.183
3/1/2011	241	335	0	335	94	-87	422	0.794	0.000	-0.206	0.794	0.740
4/1/2011	170	300	0	300	130	43	257	1.167	0.000	0.167	1.167	1.143
5/1/2011	233	287	0	287	54	97	190	1.511	0.000	0.511	1.511	1.338
6/1/2011	398	389	0	389	-9	88	301	1.292	0.000	0.292	1.292	1.226
7/1/2011	241	417	0	417	176	264	153	2.725	0.000	1.725	2.725	1.633
8/1/2011	312	443	0	443	131	395	48	9.229	0.000	8.229	9.229	1.892
9/1/2011	422	378	0	378	-44	351	27	14.000	0.000	13.000	14.000	1.929
10/1/2011	277	175	0	175	-102	249	-74	-2.365	0.000	0.899	-2.365	0.620

Table B1. Monthly Reported Planned Tasks with Actual Completed Tasks.

Data from Monthly IMS/ Known Future Task	Planned Effort (Mp)	Actual Effort (Ma)	Future Effort (Mf)	Total Effort Mt=Ma+ Mf	Monthly IMδ=Ma- Mp	SCD SIMδ=Sum(IMδ)	MTp=Mp +SIMδ	AMp=Ma /MTp	FMp=Mf/ SIMδ	IMp=SIM δ/MTp	AMp- FMp	MPIS
7/1/2009	1	1	4	5	0	0	1	1.000	4.000	0.000	-3.000	1.000
8/21/2009	73	67	4	71	-6	-6	73	0.918	-0.800	-0.082	1.718	0.952
9/25/2009	227	196	11	207	-31	-37	233	0.841	-0.306	-0.159	1.147	0.862
10/23/2009	218	201	21	222	-17	-54	255	0.788	-0.396	-0.212	1.184	0.821
11/27/2009	257	265	12	277	8	-46	311	0.852	-0.267	-0.148	1.119	0.868
12/31/2009	231	152	9	161	-79	-125	277	0.549	-0.073	-0.451	0.621	0.274
1/22/2010	139	114	23	137	-25	-150	264	0.432	-0.154	-0.568	0.586	0.031
2/19/2010	250	208	37	245	-42	-192	400	0.520	-0.194	-0.480	0.714	0.327
3/26/2010	275	334	20	354	59	-133	467	0.715	-0.152	-0.285	0.867	0.671
4/23/2010	198	123	31	154	-75	-208	331	0.372	-0.150	-0.628	0.521	-0.205
5/21/2010	197	160	35	195	-37	-245	405	0.395	-0.143	-0.605	0.539	-0.123
6/25/2010	149	195	38	233	46	-199	394	0.495	-0.192	-0.505	0.687	0.265
7/23/2010	110	146	49	195	36	-163	309	0.472	-0.302	-0.528	0.775	0.319
8/20/2010	256	197	700	897	-59	-222	419	0.470	-3.167	-0.530	3.638	0.854
9/24/2010	342	315	670	985	-27	-249	564	0.559	-2.702	-0.441	3.260	0.865
10/22/2010	353	312	570	882	-41	-290	602	0.518	-1.972	-0.482	2.491	0.807
11/26/2010	486	267	403	670	-219	-509	776	0.344	-0.793	-0.656	1.137	0.423
12/31/2010	310	324	380	704	14	-495	819	0.396	-0.769	-0.604	1.165	0.481
1/28/2011	222	176	367	543	-46	-541	717	0.245	-0.680	-0.755	0.925	0.184
2/25/2011	169	165	290	455	-4	-545	710	0.232	-0.533	-0.768	0.765	-0.003
3/31/2011	219	195	504	699	-24	-569	764	0.255	-0.887	-0.745	1.143	0.348
4/29/2011	163	221	580	801	58	-511	732	0.302	-1.137	-0.698	1.439	0.515
5/27/2011	229	194	665	859	-35	-546	740	0.262	-1.220	-0.738	1.482	0.502
6/30/2011	398	417	623	1040	19	-527	944	0.442	-1.184	-0.558	1.626	0.657
7/29/2011	242	289	727	1016	47	-480	769	0.376	-1.518	-0.624	1.894	0.670
8/26/2011	304	363	815	1178	59	-421	784	0.463	-1.940	-0.537	2.403	0.777
9/30/2011	421	454	741	1195	33	-388	842	0.539	-1.915	-0.461	2.454	0.812

Table B2. IMS Calculated Planned Tasks with Actual Completed Tasks and Actual Completed Future Tasks.

APPENDIX C. PROGRAM STATUS WITH SPI, CPI, MPI, AND RAI

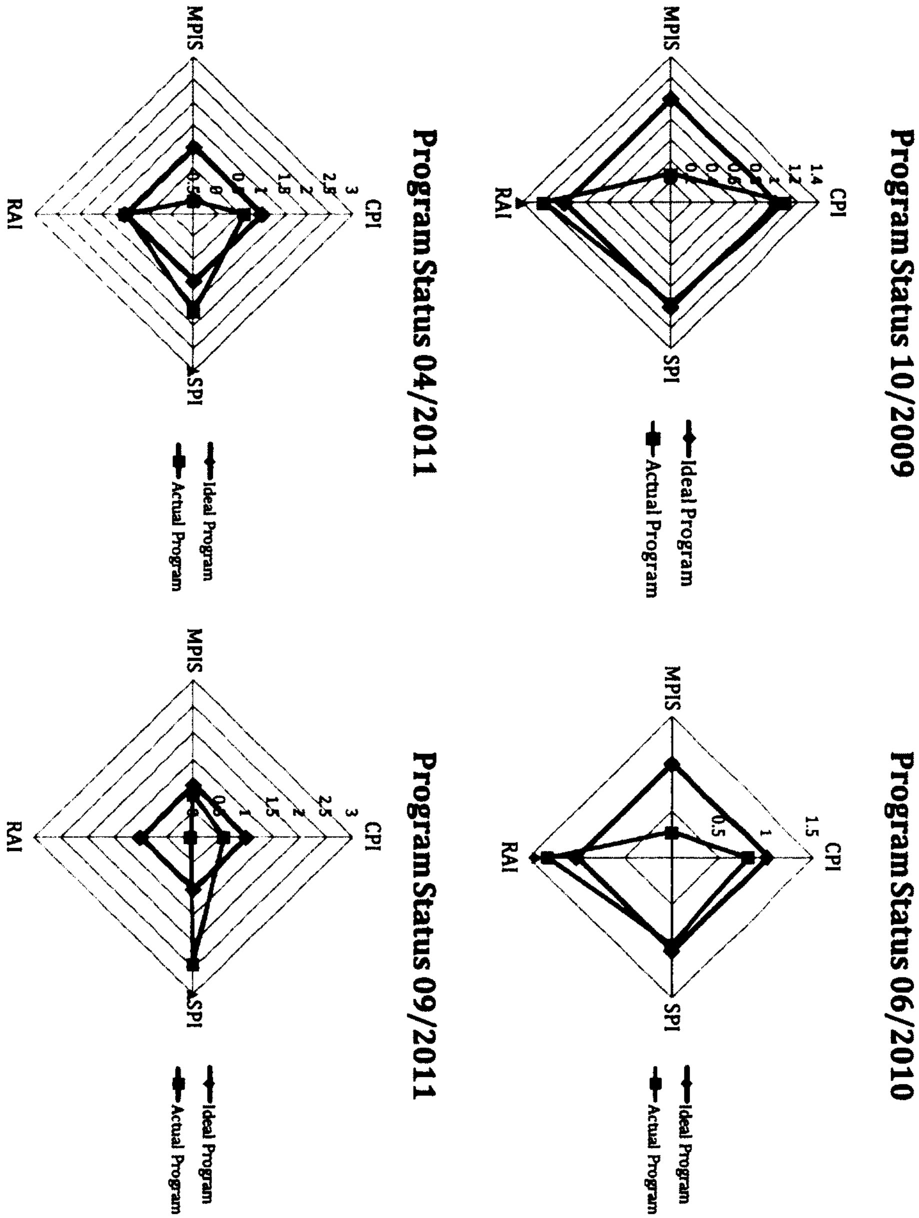


Figure C 1. Program Status Graphs.

Note: Ideal program value is set to 1.0 in all graphs. Differences in graphs are due to actual program data scaling.

APPENDIX D. EVM CALCULATION EXAMPLES

4/29/2011

WBS	Description	BAC	BCWS	BCWP	ACWP	SPI	CPI	ETC	EAC	VAC	BCWS/ETC VAC
1.1.1	MP1	0.0805	0.0492	0.0539	0.0640	1.1000	0.8400	0.0183	0.0823	-0.0018	-3.31%
1.1.2	CFE	0.0771	0.0485	0.0509	0.0670	1.0500	0.7600	0.0188	0.0857	-0.0086	-3.72%
1.1.3	ARF A1	0.0826	0.0294	0.0339	0.0404	1.1500	0.8400	0.0395	0.0799	0.0026	-5.05%
1.1.5	AT1	0.1074	0.1053	0.0865	0.0909	0.8200	0.9500	0.0215	0.1124	-0.0050	-0.71%
1.1.6	IAT&C A	0.0824	0.0621	0.0427	0.0531	0.6900	0.8000	0.0378	0.0909	-0.0084	-2.88%
1.2.1	RTP1	0.1162	0.1041	0.1056	0.1448	1.0100	0.7300	0.0110	0.1558	-0.0396	-5.17%
1.2.2	CVD	0.0047	0.0047	0.0028	0.0064	0.6100	0.4400	0.0026	0.0090	-0.0043	-0.43%
1.2.3	S1DA	0.0528	0.0354	0.0378	0.0526	1.0700	0.7200	0.0149	0.0675	-0.0148	-3.21%
1.2.4	S1OA	0.0051	0.0047	0.0047	0.0032	1.0000	1.5000	0.0003	0.0034	0.0016	0.13%
1.2.5	ARF S1	0.0252	0.0217	0.0219	0.0290	1.0100	0.7600	0.0043	0.0333	-0.0081	-1.15%
1.2.6	IAT&C S	0.0767	0.0586	0.0452	0.0734	0.7700	0.6200	0.0432	0.1166	-0.0398	-5.79%
1.3.2	PM SE RDT&E	0.1498	0.1106	0.1105	0.1624	1.0000	0.6800	0.0334	0.1964	-0.0466	-8.58%
1.6.1	TP	0.0036	0.0036	0.0036	0.0041	1.0000	0.8600	0.0002	0.0043	-0.0007	-0.07%
1.6.2	SD-LD	0.0211	0.0159	0.0159	0.0132	1.0000	1.2000	0.0049	0.0181	0.0030	-0.22%
Sum	Calculated	0.8852	0.6540	0.6160	0.8045	0.9486	0.8357	0.2506	1.0557	-0.1705	-40.17%
Reported	Report 4/29/11	0.8852	0.6540	0.6160	0.8045	0.9400	0.7700	0.2506	1.0557	-0.1705	-40.17%
COM		0.0036	0.0026	0.0024	0.0020	0.9200	1.2200	0.0005	0.0025	0.0011	0.02%
G&A A		0.1112	0.0828	0.0779	0.1034	0.9400	0.7500	0.0351	0.1385	-0.0274	-5.57%
PMB	Performance Measurement Baseline	1.0000	0.7394	0.6964	0.9099	0.9362	0.9352	0.2862	1.1967	-0.1967	-45.73%

Table D1. WBS April Calculations.

9/1/2011

WBS	Description	BAC	BCWS	BCWP	ACWP	SPI	CPI	ETC	EAC	VAC	BCWS/ETC VAC
1.1.1	MP1	0.0805	0.0492	0.0539	0.0640	1.1000	0.8400	0.0183	0.0823	-0.0018	-3.31%
1.1.2	CFE	0.0771	0.0485	0.0509	0.0670	1.0500	0.7600	0.0188	0.0857	-0.0086	-3.72%
1.1.3	ARF A1	0.0826	0.0294	0.0339	0.0404	1.1500	0.8400	0.0395	0.0799	0.0026	-5.05%
1.1.5	AT1	0.1074	0.1053	0.0865	0.0909	0.8200	0.9500	0.0215	0.1124	-0.0050	-0.71%
1.1.6	IAT&C A	0.0824	0.0621	0.0427	0.0531	0.6900	0.8000	0.0378	0.0909	-0.0084	-2.88%
1.2.1	RTP1	0.1162	0.1041	0.1056	0.1448	1.0100	0.7300	0.0110	0.1558	-0.0396	-5.17%
1.2.2	CVD	0.0047	0.0047	0.0028	0.0064	0.6100	0.4400	0.0026	0.0090	-0.0043	-0.43%
1.2.3	S1DA	0.0528	0.0354	0.0378	0.0526	1.0700	0.7200	0.0149	0.0675	-0.0148	-3.21%
1.2.4	S1OA	0.0051	0.0047	0.0047	0.0032	1.0000	1.5000	0.0003	0.0034	0.0016	0.13%
1.2.5	ARF S1	0.0252	0.0217	0.0219	0.0290	1.0100	0.7600	0.0043	0.0333	-0.0081	-1.15%
1.2.6	IAT&C S	0.0767	0.0586	0.0452	0.0734	0.7700	0.6200	0.0432	0.1166	-0.0398	-5.79%
1.3.2	PM SE RDT&E	0.1498	0.1106	0.1105	0.1624	1.0000	0.6800	0.0334	0.1964	-0.0466	-8.58%
1.6.1	TP	0.0036	0.0036	0.0036	0.0041	1.0000	0.8600	0.0002	0.0043	-0.0007	-0.07%
1.6.2	SD-LD	0.0211	0.0159	0.0159	0.0132	1.0000	1.2000	0.0049	0.0181	0.0030	-0.22%
Sum	Calculated	0.8852	0.6540	0.6160	0.8045	0.9486	0.8357	0.2506	1.0557	-0.1705	-40.17%
Reported	Report 4/29/11	0.8852	0.6540	0.6160	0.8045	0.9400	0.7700	0.2506	1.0557	-0.1705	-40.17%
COM		0.0036	0.0026	0.0024	0.0020	0.9200	1.2200	0.0005	0.0025	0.0011	0.02%
G&A A		0.1112	0.0828	0.0779	0.1034	0.9400	0.7500	0.0351	0.1385	-0.0274	-5.57%
PMB	Performance Measurement Baseline	1.0000	0.7394	0.6964	0.9099	0.9362	0.9352	0.2862	1.1967	-0.1967	-45.73%

Table D2. WBS September Calculations.

WBS	Description	4/29/2011 BCWS1/ EAC1 VAR	9/1/2011 BCWS2/ ETC2 VAR	9/1/2011 BCWS1/ ETC2 VAR
1.1.1	MP1	-3.31%	-2.75%	-3.58%
1.1.2	CFE	-3.72%	-4.10%	-4.79%
1.1.3	ARF A1	-5.05%	-4.90%	-5.69%
1.1.5	AT1	-0.71%	-0.63%	-0.69%
1.1.6	IAT&C A	-2.88%	-3.00%	-4.36%
1.2.1	RTP1	-5.17%	-6.18%	-6.42%
1.2.2	CVD	-0.43%	-0.52%	-0.52%
1.2.3	S1DA	-3.21%	-3.59%	-4.17%
1.2.4	S1OA	0.13%	0.08%	0.07%
1.2.5	ARF S1	-1.15%	-1.64%	-1.69%
1.2.6	IAT&C S	-5.79%	-5.50%	-6.80%
1.3.2	PM SE RDT&E	-8.58%	-9.19%	-10.84%
1.6.1	TP	-0.07%	-0.08%	-0.09%
1.6.2	SD-LD	-0.22%	-0.05%	-0.21%

Sum	Calculated	-40.17%	-42.04%	-49.78%
Reported	Report 4/29/11			
COM		0.02%	0.03%	-0.01%
G&A A		-5.57%	-5.97%	-6.92%

PMB	Performance Measurement Baseline	-45.73%	-47.98%	-56.71%

Table D3. WBS Composite Calculations.

APPENDIX E. CONTRACT ELEMENTS AND CONTRACT CONSIDERATIONS

Comparison of Major Contract Types

	Firm Fixed-Price (FFP)	Fixed-Price Economic Price Adjustment (FPEPA)	Fixed-Price Incentive Firm (FPIF)	Fixed-Price Award-fee (FPAF)	Fixed-Price Prospective Redetermination (FPRP)
Principal Risk to be Mitigated	None. Thus, the contractor assumes all cost risk.	Unstable market prices for labor or material over the life of the contract.	Moderately uncertain contract labor or material requirements.	Risk that the user will not be fully satisfied because of judgmental acceptance criteria.	Costs of performance after the first year because they cannot be estimated with confidence.
Use When..	• The requirement is well-defined. • Contractors are experienced in meeting it. • Market conditions are stable. • Financial risks are otherwise insignificant.	The market prices at risk are severable and significant. The risk stems from industry-wide contingencies beyond the contractor's control. The dollars at risk outweigh the administrative burdens of an FPEPA.	A ceiling price can be established that covers the most probable risks inherent in the nature of the work. The proposed profit sharing formula would motivate the contractor to control costs to and meet other objectives.	Judgmental standards can be fairly applied by an Award-fee panel. The potential fee is large enough to both: • Provide a meaningful incentive. • Justify related administrati ve burdens.	The Government needs a firm commitment from the contractor to deliver the supplies or services during subsequent years. The dollars at risk outweigh the administrative burdens of an FPRP.
Elements	A firm fixed-price for each line item or one or more groupings of line items.	A fixed-price, ceiling on upward adjustment, and a formula for adjusting the price up or down based on: • Established prices. • Actual labor or material costs. • Labor or material indices.	• A ceiling price • Target cost • Target profit • Delivery, quality, and/or other performance targets (optional) • Profit sharing formula	• A firm fixed-price. • Standards for evaluating performanc e. • Procedures for calculating a fee based on performanc e against the standards	• Fixed-price for the first period. • Proposed subsequent periods (at least 12 months apart). • Timetable for pricing the next period(s).
Contractor is Obliged to:	Provide an acceptable deliverable at the time, place and price specified in the contract.	Provide an acceptable deliverable at the time and place specified in the contract at the adjusted price.	Provide an acceptable deliverable at the time and place specified in the contract at or below the ceiling price.	Perform at the time, place, and the price fixed in the contract.	Provide acceptable deliverables at the time and place specified in the contract at the price established for each period.

	Firm Fixed-Price (FFP)	Fixed-Price Economic Price Adjustment (FPEPA)	Fixed-Price Incentive Firm (FPIF)	Fixed-Price Award-fee (FPAF)	Fixed-Price Prospective Redetermination (FPRP)
Contractor Incentive *(other than maximizing goodwill)* [1]	Generally realizes an additional dollar of profit for every dollar that costs are reduced.	Generally realizes an additional dollar of profit for every dollar that costs are reduced.	Realizes a higher profit by completing the work below the ceiling price and/or by meeting objective performance targets.	Generally realizes an additional dollar of profit for every dollar that costs are reduced; earns an additional fee for satisfying the performance standards.	For the period of performance, realizes an additional dollar of profit for every dollar that costs are reduced.
Typical Application	Commercial supplies and services.	Long-term contracts for commercial supplies during a period of high inflation	Production of a major system based on a prototype	Perfromance-based service contracts.	Long-term production of spare parts for a major system.
Principal Limitations in FAR Parts 16, 32, 35, and 52	Generally NOT appropriate for R&D.	Must be justified.	Must be justified. Must be negotiated. Contractor must have an adequate accounting system. Cost data must support targets.	Must be negotiated.	MUST be negotiated. Contractor must have an adequate accounting system that supports the pricing periods. Prompt redeterminations.
Variants	Firm Fixed-price Level of Effort.		Successive Targets		Retroactive Redetermination

Retrieved from

www.acq.osd.mil/dpap/ccap/.../**Contract**.../**contract** type table.doc

Contract Category Characteristics

	COST-REIMBURSEMENT	FIXED-PRICE
PROMISE	Best Effort	Shall Deliver
RISK TO CONTRACTORS	Low	High
RISK TO GOVERNMENT	High	Low
CASH FLOW	As Incurred	On Delivery
PROGRESS PAYMENTS	None	% of Actual
ADMINISTRATION	Max Government	Min Government
FEE/PROFIT	Max 15/10 % CPFF 6 % A - E Contracts	NO Limit, Except 6 % A - E Contracts

DAG 11.3.3.2 Incentivizing Higher Quality in Contracts

Contract incentives can be structured to ensure quality by contributing to the contractor's value proposition. Factors that are typically important aspects of a contractor's value proposition include:

- Customer satisfaction;
- Planning stability;
- Good financial performance; and
- Improved cash flow.

Listed below are examples of contract incentives that can be made available to the prime contractor and the prime contractor can in turn make available to subcontractors under the appropriate conditions:

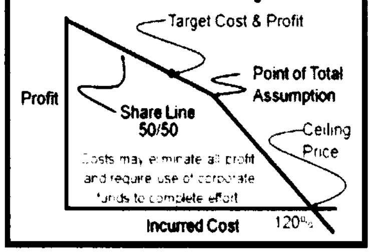
- Increased fee;
- Extended contract length;
- Follow-on contracts awarded;
- Accelerated progress payments;
- Shared savings; and
- Opportunities for return on investments (some of which may increase the contractor's competitiveness on other contracts).

Negotiating Contract Type

FAR 16.103(a)

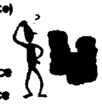
- Selecting the contract type is generally a matter for negotiation.
  - Requires the exercise of sound judgment.
- Negotiating contract type and prices are closely related and should be considered together.
- The objective is to negotiate a contract type and price (or estimated cost and fee)
  - That will result in reasonable contractor risk.
  - Provide the contractor with the greatest incentive for efficient and economical performance.

Fixed-Price-Incentive Contracts



Budget Implications

(Budget to Most Likely Price)



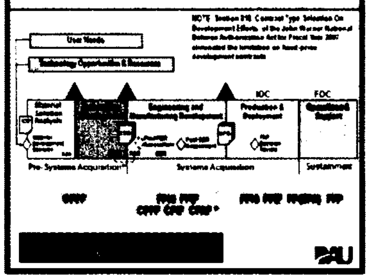
Contract Type	Budget To
FFP	Negotiated Price
FP-EPA	Negotiated Price (do not budget for EPA)
FPIF	Target Cost + Target Profit
CPFF	Estimated Cost + Fixed Fee
CPAF	Estimated Cost + Base Fee + Maximum Award Fee
CPIF	Target Cost + Target Fee

FAR 7.105 Contents of Written Acquisition Plans

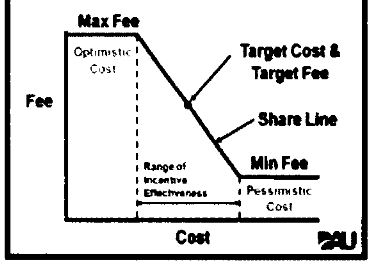
(b) *Plan of action* –

(3) *Contract type selection.* Discuss the rationale for the selection of contract type. For other than firm-fixed-price contracts, see 16.103(d) for additional documentation guidance. Acquisition personnel shall document the acquisition plan with findings that detail the particular facts and circumstances, (e.g., complexity of the requirements, uncertain duration of the work, contractor's technical capability and financial responsibility, or adequacy of the contractor's accounting system), and associated reasoning essential to support the contract type selection. The contracting officer shall ensure that requirements and technical personnel provide the necessary documentation to support the contract type selection.

"Typical" Contract Types by Phase



Cost-Plus-Incentive-Fee Contracts



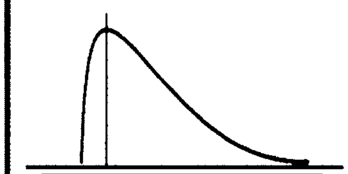
Acquisition Strategy and Acquisition Plan

- Defense Acquisition Guidebook
  - 2.3 Systems Acquisition: Acquisition Strategy
    - 2.3.10.2.4.1 Contract Type Selection
    - 2.3.10.2.6 Contract Incentives
- Federal Acquisition Regulation and Defense Federal Acquisition Regulation Supplement
  - FAR Part 7 – Acquisition Planning
  - FAR Part 16 – Types of Contract

FAR Policies on Contract Type

- The cost-plus-a-percentage-of-cost system of contracting shall not be used.
- Commercial contracts under FAR Part 12 shall be firm-fixed-price contracts or fixed-price contracts with economic price adjustment. A time-and-materials contract or labor-hour contract may be used for the acquisition of commercial services under limited conditions.
- Sealed bid contracts under FAR Part 14 shall be firm-fixed-price contracts or fixed-price contracts with economic price adjustment.
- Contracts negotiated under Part 15 may be of any type or combination of types.

Distribution of Cost Outcomes Does Not Follow a Bell Shaped Curve



There is limited potential for underrun, but infinite potential for overrun.

16.301-3 Limitations on Cost-Reimbursement Contracts

(a) A cost-reimbursement contract may be used only when–

– Additional Requirement –

(4) Prior to award of the contract or order, adequate Government resources are available to award and manage a contract other that firm-fixed-priced (see 7.104(e)). This includes appropriate Government surveillance during performance in accordance with 1.602-2, to provide reasonable assurance that efficient methods and effective cost controls are used.

(i) Designation of at least one contracting officer's representative (COR) qualified in accordance with 1.602-2 has been made prior to award of the contract or order; and

(ii) Appropriate Government surveillance during performance to provide reasonable assurance that efficient methods and effective cost controls are used.

Acquisition Strategy

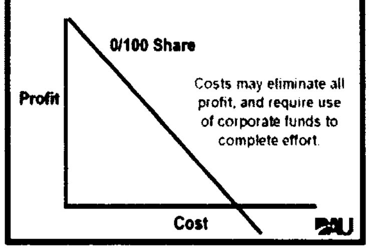
2.3.10.2.6. Contract Incentives

In the Contract Incentives section, the Acquisition Strategy should explain the planned contract incentive structure and how the PM plans to employ contract incentives to achieve required cost, schedule, and performance outcomes. If more than one incentive is planned for a contract, the Acquisition Strategy should explain how the incentives complement each other and do not interfere with one another.

FAR 16.104 Factors in Selecting Contract Types

- Price competition.
- Price analysis.
- Cost analysis.
- Type and complexity of the requirement.
- Combining contract types.
- Urgency of the requirement.
- Period of performance or length of production run.
- Contractor's technical capability and financial responsibility.
- Adequacy of the contractor's accounting system.
- Concurrent contracts.
- Extent and nature of proposed subcontracting.
- Acquisition history.

Firm-Fixed-Price Contracts



Guidance on Contract Types and Incentives

Contract Pricing Reference Guides

Contract Cost, Price & Finance CoP

Incentive Strategies for Defense Acquisitions

Constructing Successful Business Relationships: Innovation in Contractual Incentives

DOD and NASA Guide: Incentive Contracting Guide, 1969

VITA Henry Darrel Webb 13 June 2012

Day Phone: 540-775-4979
Email: henry.webb@navy.mil

EDUCATION

Doctorate of Engineering, Old Dominion University: Graduation August 2012: 4.0

GPA in doctoral level work.

Doctoral project: Meta-Heuristics Analysis for Technologically Complex Programs:

Understanding the Impact of Total Constraints for Schedule, Quality and Cost

Doctor of Engineering Course of Study

- Methods for Rational Decision Making
- System Architectures & Modeling
- Engineering Ethics
- Introduction to Systems Engineering
- Multi-Criteria Decision Analysis and Decision Support Systems
- Systems Safety
- Complexity, Engineering & Management
- Requirements Management Verification and Validation
- Introduction to Modeling and Simulation
- Financial Engineering
- Risk Management
- Crisis Project Management

MAJOR WORK BACKGROUND AREAS

Department of Defense US Navy

- Non-Lethal Weapons,
- Data Links & Communications
- Software Development
- Hardware Control
- Electronic Intelligence, Communications Intelligence & Signal Processing.